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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON THE

GEOLOGY AND WATER RESOURCES OF NEBRASKA WEST OF THE ONE HUNDRED AND THIRD MERIDIAN

BY

NELSON HORATIO DARTON

WASHINGTON
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PRELIMINARY REPORT ON THE GEOLOGY AND WATER RESOURCES OF NEBRASKA WEST OF THE ONE HUNDRED AND THIRD MERIDIAN.[a]

By Nelson Horatio Darton.

INTRODUCTION.

This report is based on field work of the season of 1897. It is designed mainly to furnish information in relation to the geologic structure and the prospects for underground waters. A general account will also be given of the surface waters and their present and prospective use for irrigation, etc. The region is the portion of Nebraska lying west of the one hundred and third meridian, comprising Sioux, Scotts Bluff, Banner, and Kimball counties, the western portions of Cheyenne and Boxbutte counties, and the central and western portion of Dawes County; in all, an area of 7,400 square miles, adjoined on the west by Wyoming, on the north by South Dakota, and on the south by Colorado. It lies on the Great Plains south of the Black Hills of South Dakota. The Scotts Bluff, Banner, and Cheyenne counties areas were examined in detail, but time did not permit more than a general reconnaissance of the adjoining regions. I was assisted by Mr. C. A. Fisher, who obtained the data for the greater part of Kimball and Boxbutte counties. For several months I was accompanied by Prof. E. H. Barbour, the acting State geologist of Nebraska, who did much to further the progress of the work.

Numerous data in regard to irrigation in the Niobrara River, White River, and Hat Creek basins were kindly furnished by Mr. J. M. Wilson, the State engineer.

TOPOGRAPHY.

General features.—The region is a typical portion of the Great Plains, which extend far eastward from the foot of the Rocky Mountains. To the south this portion of the plains is traversed by the deep, broad valley of North Platte River and the smaller valleys of Niobrara River and Lodgepole Creek; to the north, at the valleys of White River and Hat Creek, it gives place to lowlands extending to Cheyenne River at the southern foot of the Black Hills. The northern edge of the plains presented toward these lowlands is marked by a great escarpment, or line of steep slopes, which is known as Pine Ridge. It begins in Wyoming and is the most conspicuous topographic feature in northwestern Nebraska.

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[a] This is a reprint of the paper in the Nineteenth Annual Report of the United States Geological Survey, 1897-98, Part IV, pp. 719-785, Plates LXXIV-CXVIII, published in 1899. In the present edition there are only a few corrections in some of the maps and a few minor changes in statements regarding geology. An index has been added and there is new pagination and renumbering of plates and figures.

Pl. XI has for its base a topographic map of the region, with contour lines 100 feet apart. These contour lines indicate heights above the sea, and they are numbered accordingly. The lines for every even 500 feet are made heavier than the others. Contour lines are lines of equal elevation, consequently they are drawn along the slopes of valleys like level irrigation ditches, in this case 100 feet apart vertically, extending up the side valleys, and running out around the points of projections. They encircle detached hills, and an isolated hill rising 500 feet above the plain would be indicated by five of the 100-foot contour lines. From the foregoing statement, it will be seen that contour lines are crowded near together on steep slopes, but are widely separated on the plains and in the river bottoms. Thus, they indicate the shape of the land as well as its elevation.

For Banner, Scotts Bluff, and portions of Cheyenne and Sioux counties, the contour map is based on the detailed maps, with 20-foot contour lines, of the Scotts Bluff,[a] Camp Clarke,[a] and Whistle Creek quadrangles of the United States Geological Survey. In other portions of the region it has been necessary to employ barometer readings and local observations extending from points of known heights on the several railroad lines. These approximate data are distinguished on the map by broken contour lines.

Pl. II is a view of a relief map of Nebraska, which also shows the configuration of this area.

High table.—The original surface of the region to which this report relates was a relatively smooth plain, which sloped gently to the east. This plain was uplifted in early Pleistocene time, and the rivers extending across it excavated valleys of greater or less width and depth, soon giving rise to the broader features of the present configuration. The remains of the plain lie between the valleys, where they constitute wide areas of high table-lands, smooth or very gently rolling in contour, and sloping to the east. The widest areas of this table lie on each side of the valley of Lodgepole Creek, and extend north from the valley of North Platte River to the great escarpment of Pine Ridge, where there is an abrupt descent of over 1,000 feet to a region of low rolling plains which extend to Cheyenne River at the southern foot of the Black Hills. Some features of this great escarpment are shown in Pls. II, VIII, XVII, and XXI. The broad area of table terminating in Pine Ridge is

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[a] Topographic maps of these two quadrangles have recently been issued by the Survey and may be obtained by remitting 10 cents (5 cents for each) to the Director, United States Geological Survey, Washington, D. C.

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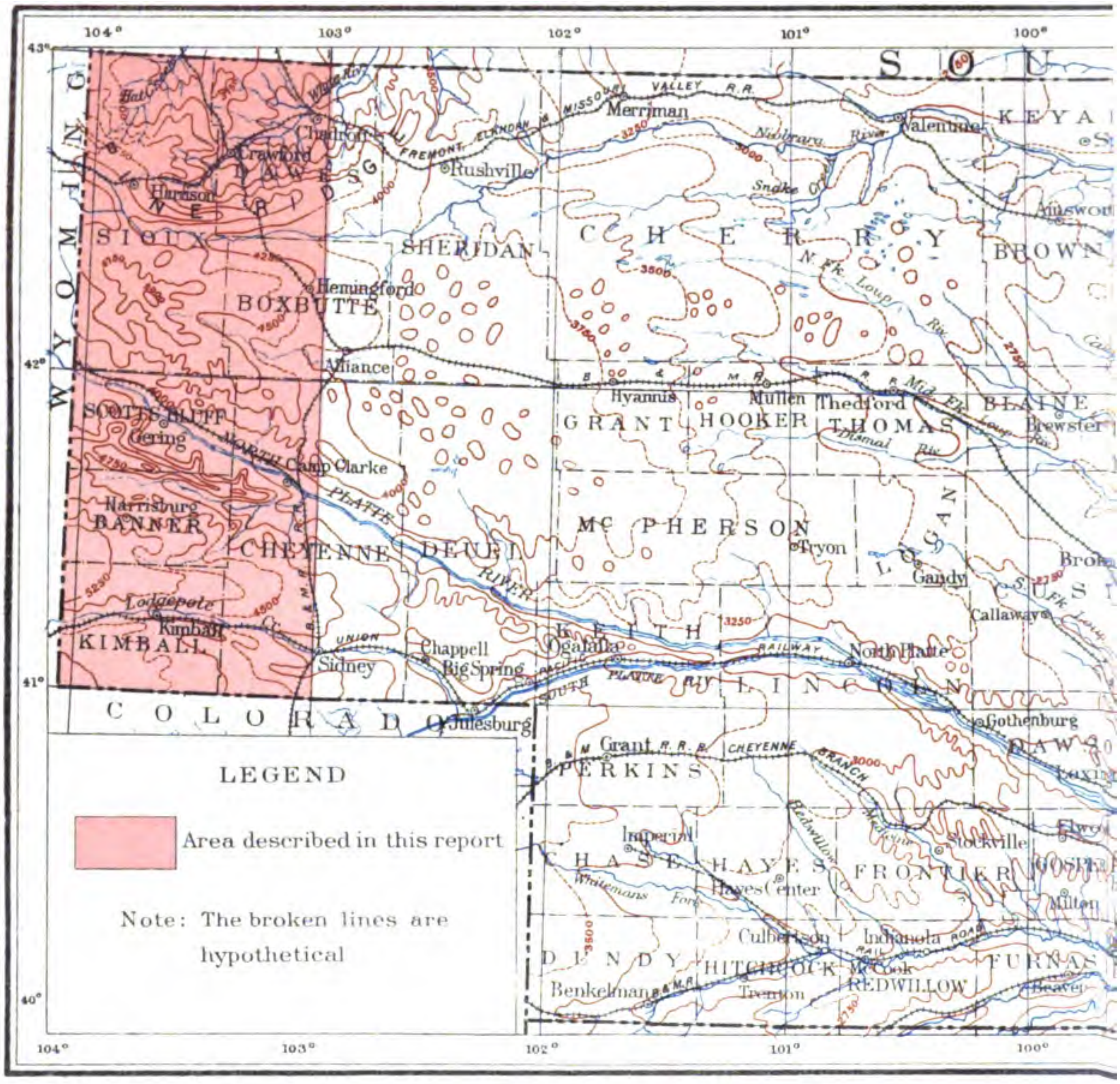


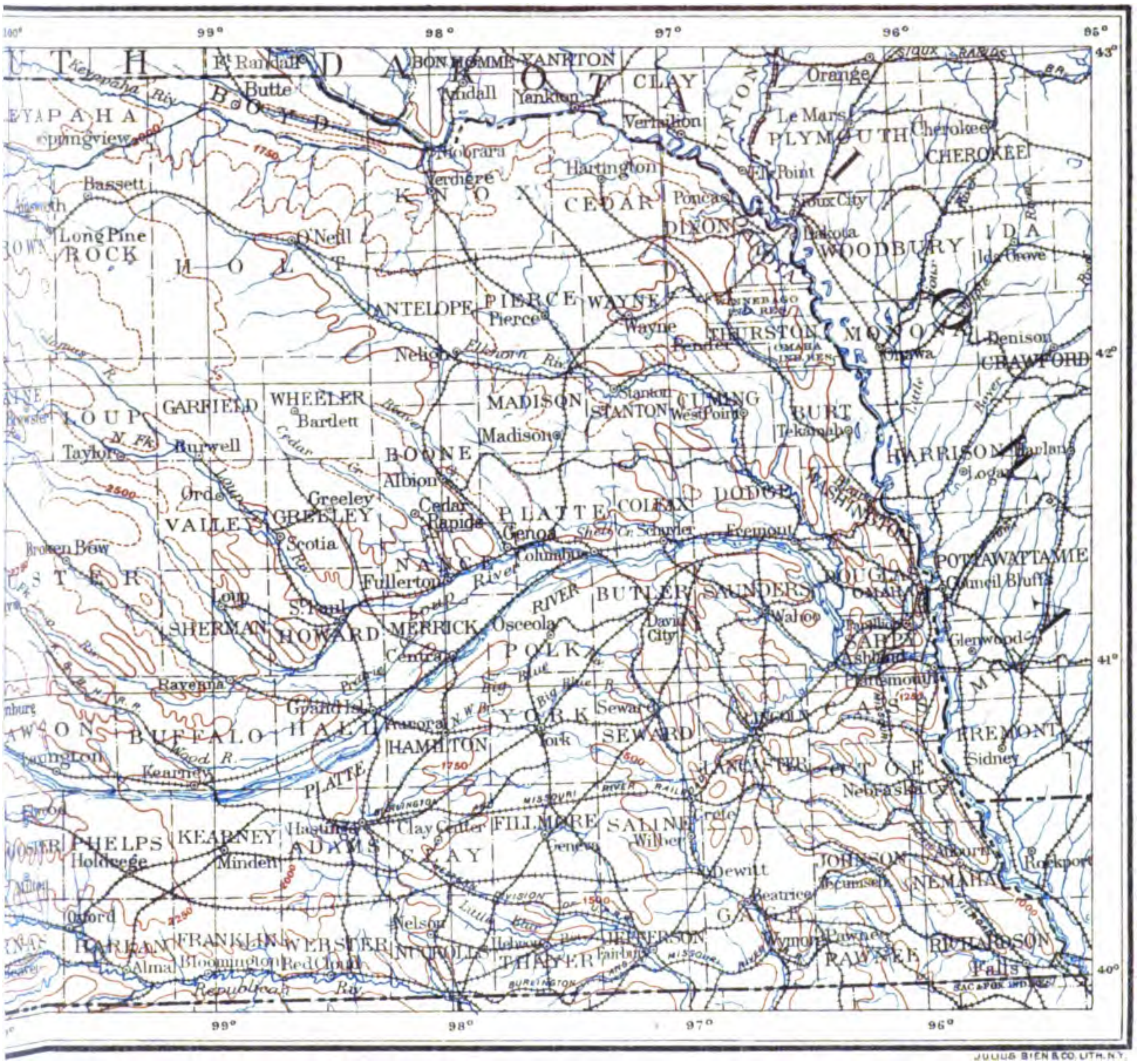
CONTOUR MAP OF NEBRASKA, COMPILED FROM U.S.

BY N. H. DART

Scale

40 20 0 40

Contour interval



[U. S. GEOLOGICAL SURVEY MAPS AND RAILROAD DATA

DARTON 1898

Scale

40 80 120 miles

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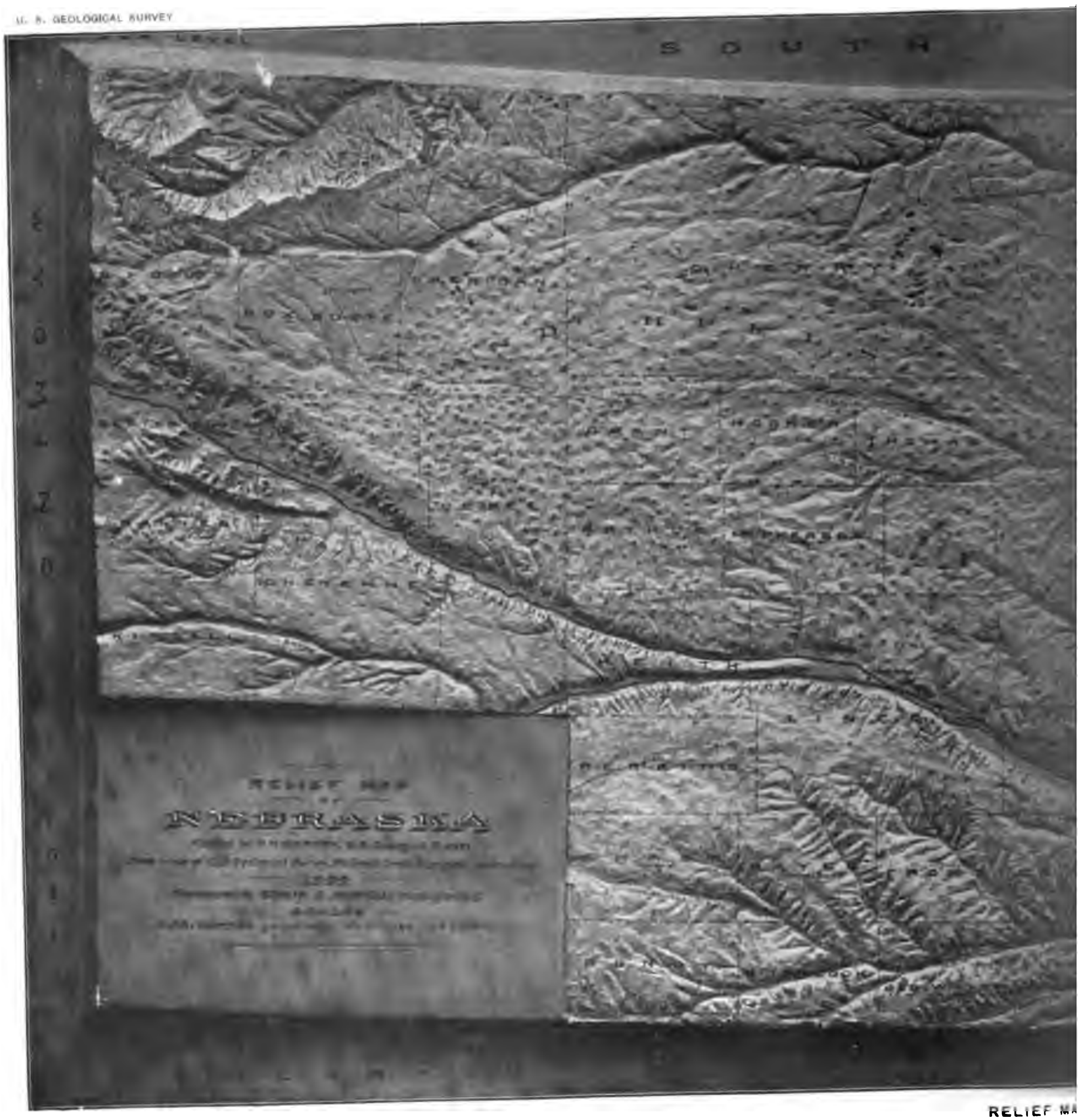
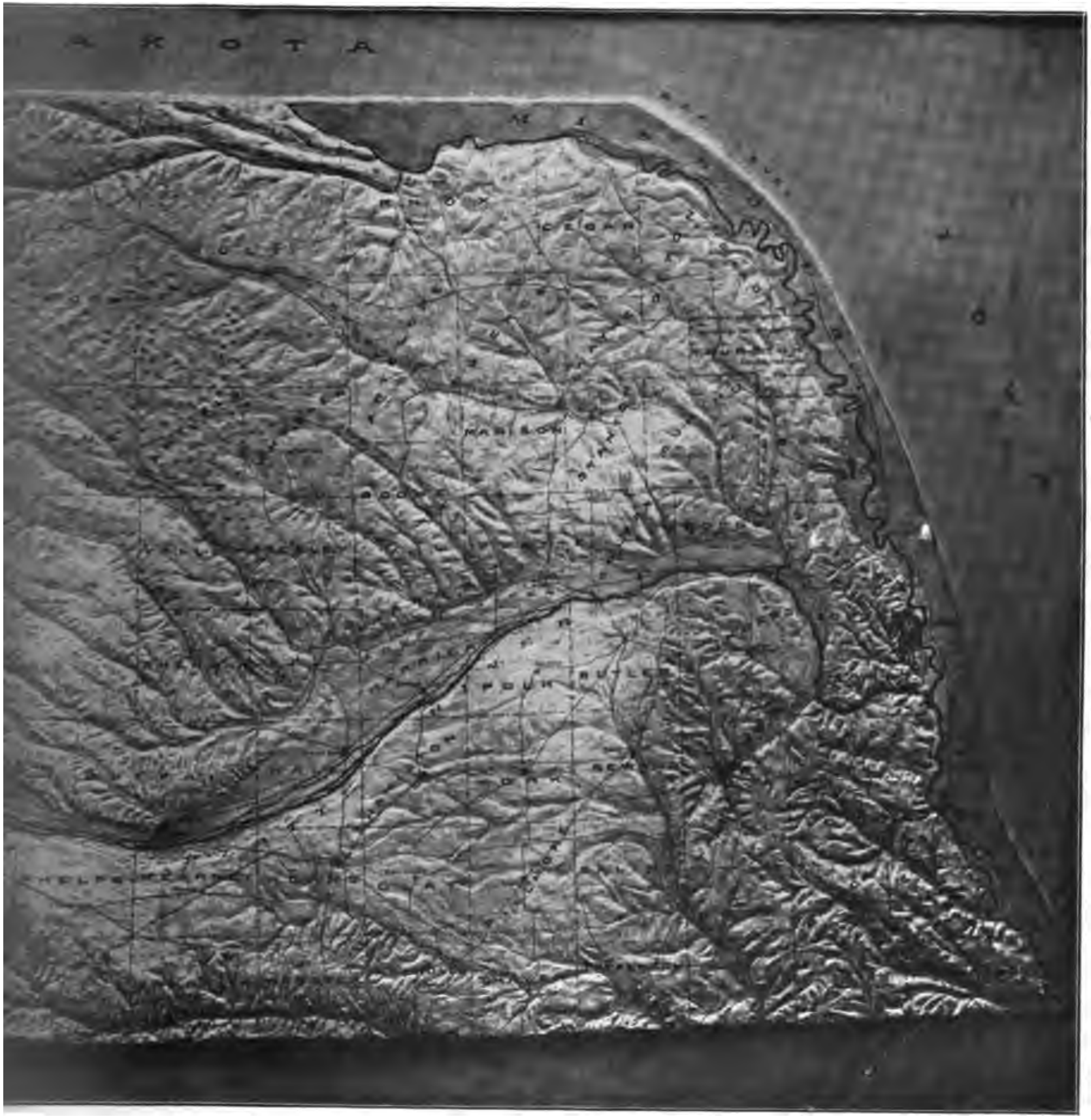


RELIEF MA



NEBRASKA.

traversed by the wide, shallow valley of the Niobrara, south of which it is surmounted by irregular zones of sand hills. The edge of the table descending to the valley of North Platte River presents steep slopes deeply notched by canyons. Next south, there is an outlying area of the high plain, preserved as a long, high, narrow ridge lying between the valleys of Pumpkinseed Creek and North Platte River. This ridge is so narrow and so deeply invaded by canyons that it has lost the flat-topped character, except in a few small areas in its widest portions. Its summits, however, in many cases rise to the plateau level. The ridge owes its isolation to a former channel of Horse Creek, which at one time flowed through the Pumpkinseed Valley. Eight miles south, across the valley of Pumpkinseed Creek, a branch of North Platte River, rises the steep face of the wide area of high table-land extending to the valley of Lodgepole Creek, and continuing beyond that valley far into Colorado. The altitudes on the table-land average about 4,300 feet along the one hundred and third meridian, and increase to nearly 5,000 feet in the vicinity of the Wyoming line. In the southwestern portion of Banner County, and again in the extreme southwestern portion of the State, the altitudes somewhat exceed 5,300 feet. Here is found the highest land in the State. Scotts Bluff has the reputation of being the highest point, but its altitude is only 4,662 feet. Wildcat Mountain, which has shared the claim as the highest point, is 5,038 feet, or fully 300 feet lower than the highest points on the high table along the Wyoming line.

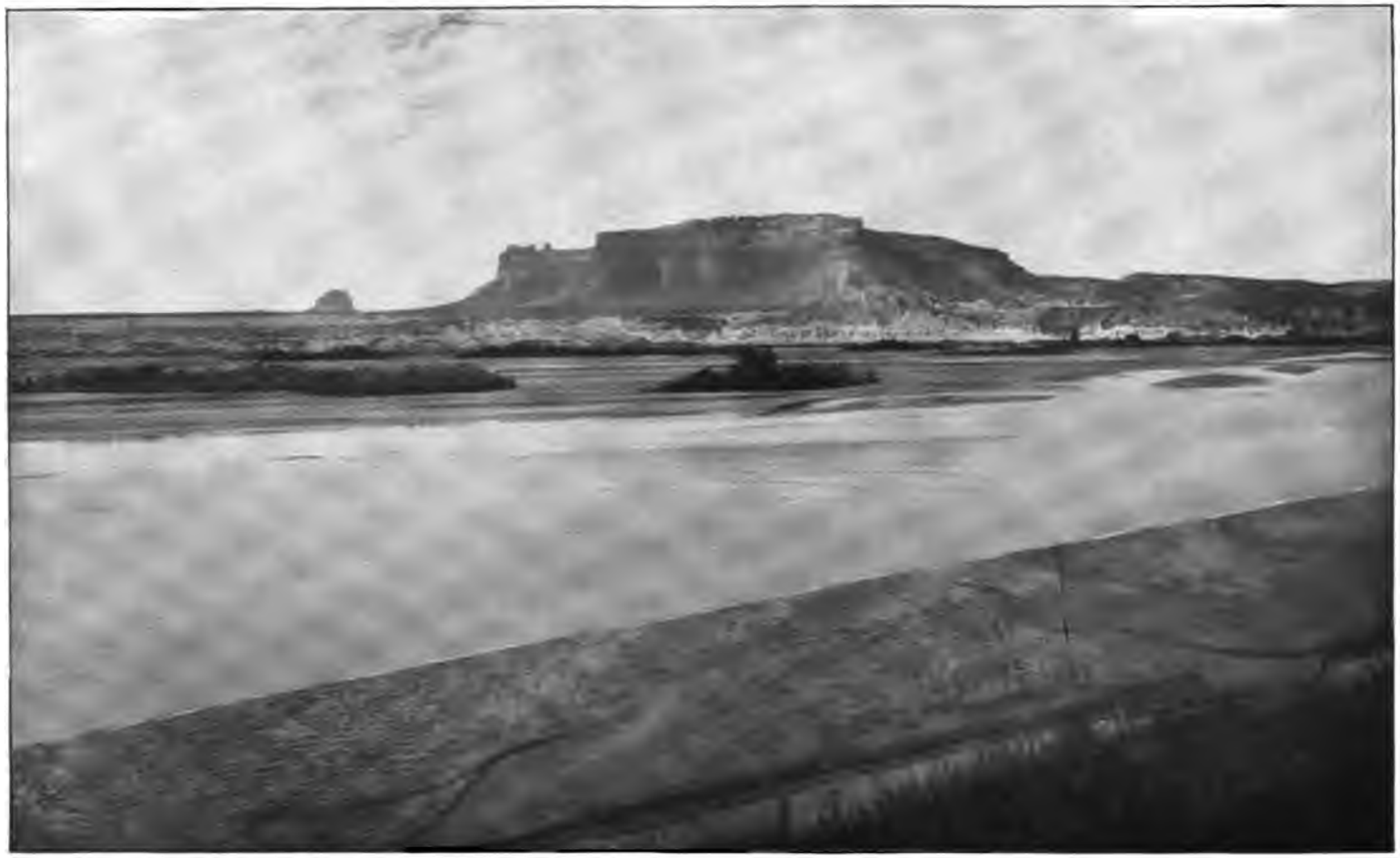
North Platte Valley.—The region is traversed near its center by the broad valley of North Platte River, a stream which enters the State from Wyoming and carries the drainage of a wide area in the Rocky Mountains. This valley has been excavated from the plain which, as before stated, originally extended unbroken entirely across the western Nebraska region. The depth of the valley averages in the greater part about 700 feet, and its width varies from 10 to 15 miles. The slopes along its sides present many irregularities. There is first a broad flat along the river, which rises only a few feet above the water. This flat merges into irregular terraces, rising for about 200 feet, with slopes of varying degrees of steepness. Then come steep-sided projections of high lands extending from the edge of the high table above and separated by canyons which are cut into the margin of the table for some distance. These canyons have been excavated by small streams which flow into Platte River in times of heavier rainfall. The higher slopes of the valley are marked by cliffs and buttes of varied form and height, which often are very imposing in appearance. On the south side of the valley there rises an irregular ridge of striking prominence, cut off from the main high table to the south by the wide valley of Pumpkinseed Creek. The greater part of this ridge varies in width from 3 to 6 miles, with long projecting spurs and occasional outlying buttes. Its crest is relatively uniform in height, about 800 feet above the bottom of the Platte Valley. In the vicinity of the Wyoming line its altitude diminishes greatly, but it is practically isolated from the high tables southward. The main axis of the ridge is about 7 miles south of the river, but several spurs extend nearly to the river. One of these terminates in Chimney Rock, shown in Pl. XXIV; another at Castle Rock, shown in Pl. XXXII; and a third at Scotts Bluff, shown in Pl. III. To the east this ridge terminates in two outlying buttes, known as Courthouse and Jail rocks, shown in Pls. IV and V. It also sends a branch ridge out into the Pumpkinseed Valley, on which there are some particularly high knobs, one of which is known as Wildcat Mountain and the other as Hogback Mountain, in which an altitude of somewhat over 5,000 feet is attained. The western part of the ridge has an altitude of 4,860 feet. Scotts Bluff has an altitude of 4,662 feet and Courthouse Rock 4,100 feet. The ridge is deeply invaded by numerous canyons, which have cut away nearly all its original tabular surface. Toward its eastern extremity its lower slopes bear extensive accumulations of sand hills, notably in the region south of Camp Clarke.

The Pumpkinseed Valley south of this ridge is elevated somewhat above the valley of North Platte River, into which it opens at Lapeer. It varies in width from 7 to 12 miles. It is characterized by gentle slopes, which extend north to the steep slopes and buttes of the ridge above described, and to the south to the cliffs and canyons at the edge of the high table. Lawrence Fork, the principal branch of Pumpkinseed Creek, occupies a valley which heads to the south and west on the surface of the table-lands.

Lodgepole Valley.—Lodgepole Creek has cut a narrow, steep-sided trough in the plains to a depth averaging 300 feet. The valley contains a flat which has a declivity of about 17 feet to the mile, having an altitude of about 4,100 feet on the one hundred and third meridian and nearly 5,000 feet at the Wyoming line. Its average width varies from 1½ to 3 miles. The principal branch is Sidney Draw, the two forks of which rise on the table-land in the vicinity of the Colorado line.

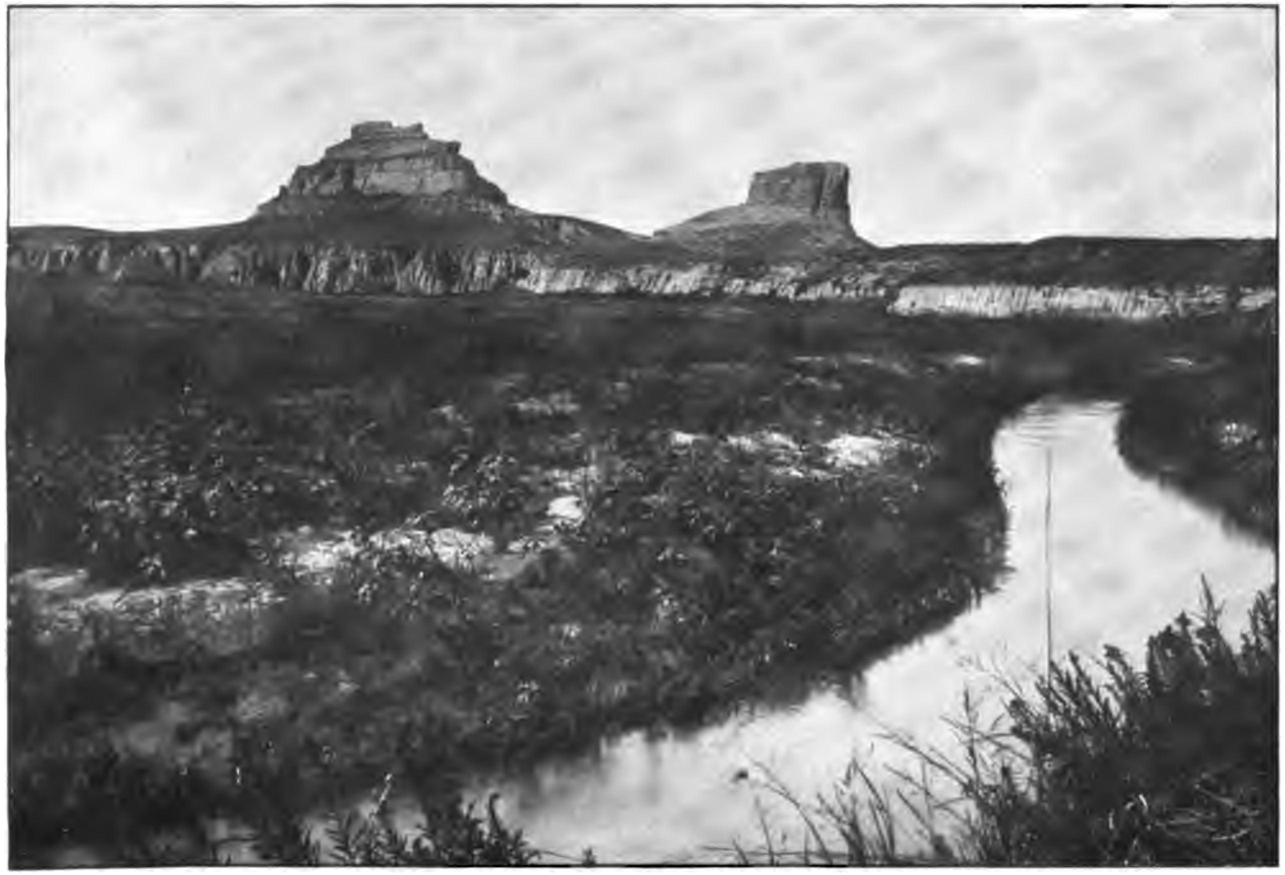
Niobrara Valley.—The Niobrara River flows in a wide, relatively shallow valley, high up on the table-lands lying between the valley of North Platte River and the crest of Pine Ridge. It enters Nebraska from Wyoming, flows southeast for 20 miles, and then nearly due east. At the Wyoming line its altitude is about 4,700 feet, and at the one hundred and third meridian about 3,900 feet, which indicates a gradient of 13 feet to the mile. The valley bottom is seldom over half a mile in width, with gentle slopes interrupted by occasional low cliffs. The bottom of the valley is only from 400 to 500 feet below the crest of Pine Ridge, and it is uniformly about 400 feet above the level of North Platte River along a north-northeast and south-southwest line, while to the north the lowlands beyond Pine Ridge are at altitudes about 600 feet lower than Niobrara River.

White River Valley.—White River rises in Pine Ridge, near Harrison, at an



SCOTTS BLUFF, FROM NORTH SIDE OF NORTH PLATTE RIVER.

Dome Rock in the distance.



COURTHOUSE AND JAIL ROCKS, FROM THE SOUTH.

Courthouse Rock irrigation canal in the foreground.

altitude of about 4,800 feet, or several hundred feet higher than Niobrara River, a short distance to the southwest. It flows to the east, and has excavated a gorge in the northern face of Pine Ridge, which has a fall of 1,100 feet in the first 20 miles, a declivity of 55 feet to the mile. Near Crawford the valley of White River merges into the rolling plains at the foot of Pine Ridge, and then extends northeast as a wide, shallow depression among rolling hills, in which its declivity is only 20 feet to the mile. Its altitude at the one hundred and third meridian is about 3,100 feet. The river receives many streams from the deep canyons in the northern front of Pine Ridge, and a number of intermittent creeks from the rolling country northward.

Hat Creek Basin.—Hat Creek is a branch of the South Fork of Cheyenne River. It rises in a canyon in the north front of Pine Ridge, in Sioux County, and receives numerous branches also heading in this front. To the east, where Pine Ridge trends southeast and passes around toward the head of White River, the divide between the Hat Creek and White River drainages is a low, narrow ridge, which projects from the spur of Pine Ridge near Adelia, and extends far to the northeast into South Dakota. The highest points on this divide beyond Round Top, the high spur of Pine Ridge, are some outlying mounds, of which the most conspicuous is the Sugar Loaf, due north of Adelia. Where the ridge is crossed by the Burlington and Missouri River Railroad, north-northwest of Adelia, the altitude is 3,816 feet. From the Sugar Loaf northeast the ridge is moderately high for some distance, and then gradually diminishes in height. It is crossed by the Deadwood line of the Fremont, Elkhorn and Missouri Valley Railway at an altitude of about 3,650 feet.

The upper portion of the Hat Creek Basin consists of deep canyons extending far into the north front of Pine Ridge. The sides of these canyons rapidly diminish in height to the north, and soon give place to a region of low rolling hills having a generally gentle slope northward. On the South Dakota line the altitude of Hat Creek is about 3,500 feet.

Sand hills.—There is in this portion of western Nebraska a narrow extension of the great sand-hill area of Nebraska. The hills are comprised in a series of detached groups that lie mainly in the northern portion of Cheyenne and the south-central portion of Sioux counties and cover an area of about 300 square miles. Their distribution is shown on the map, Pl. XI. The hills are mainly from 50 to 150 feet in height, and the areas consist of assemblages of irregular dunes with intervening basins and valleys. In T. 26, R. 55, and T. 27, R. 56, there are some exceptionally high sand hills, which rise somewhat over 5,000 feet in altitude, or from 200 to 250 feet above the surrounding plain. The lower dunes are in greater part covered with a scanty growth of grass, but there are many areas of considerable extent in which the sand is bare and loose. These localities are generally "blowouts" on the northwest slopes of the larger dunes. There is an extensive local sand-hill area along the south side of the valley of North Platte River, on the slopes south of Camp Clarke, which extends as far eastward as the vicinity of Courthouse Rock. The width of this belt is but 5 miles at most, and its length about 15 miles. An area of smaller size lies just west of Chimney Rock.

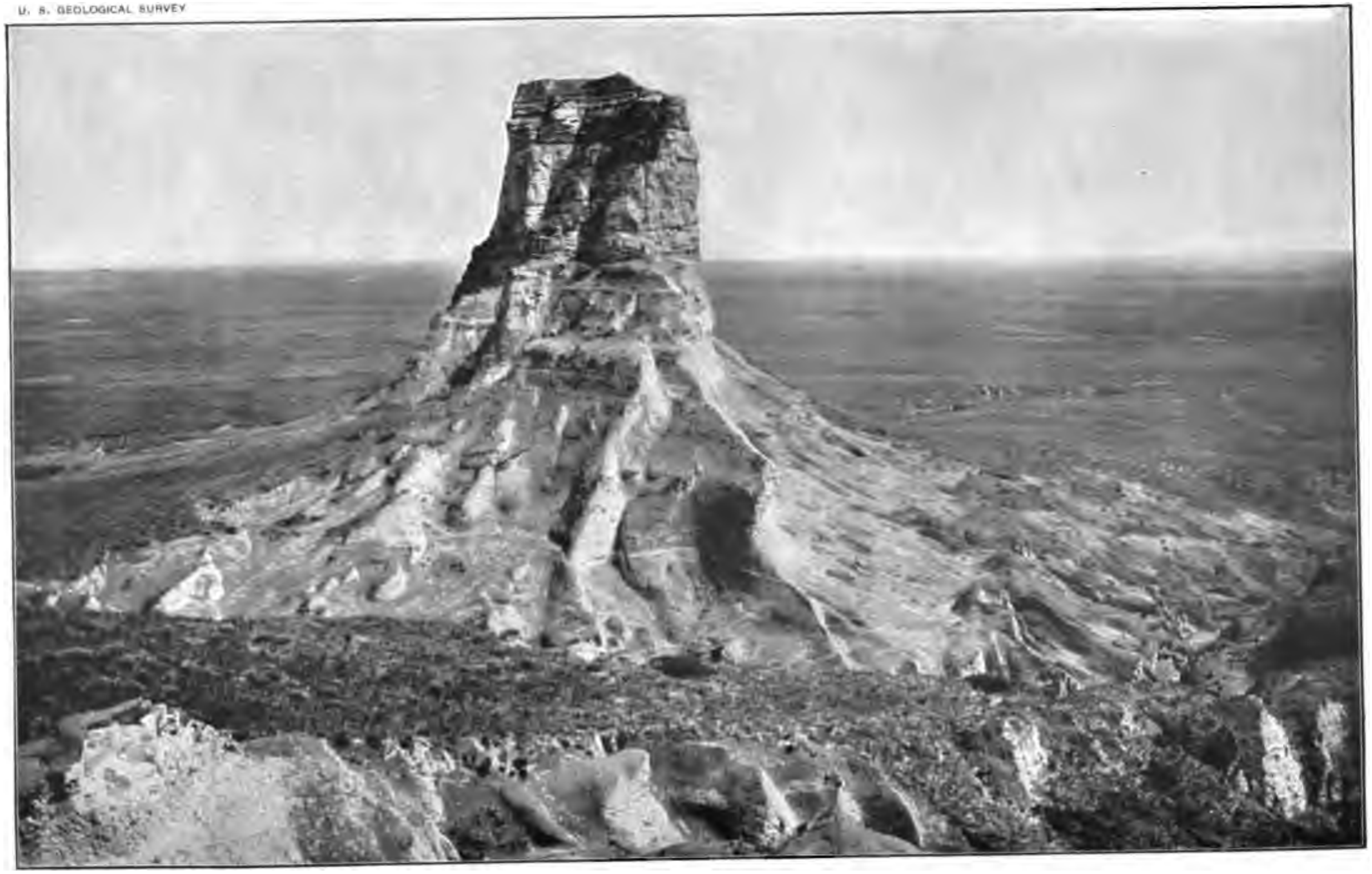
GEOLOGY.

GENERAL GEOLOGY OF NEBRASKA.

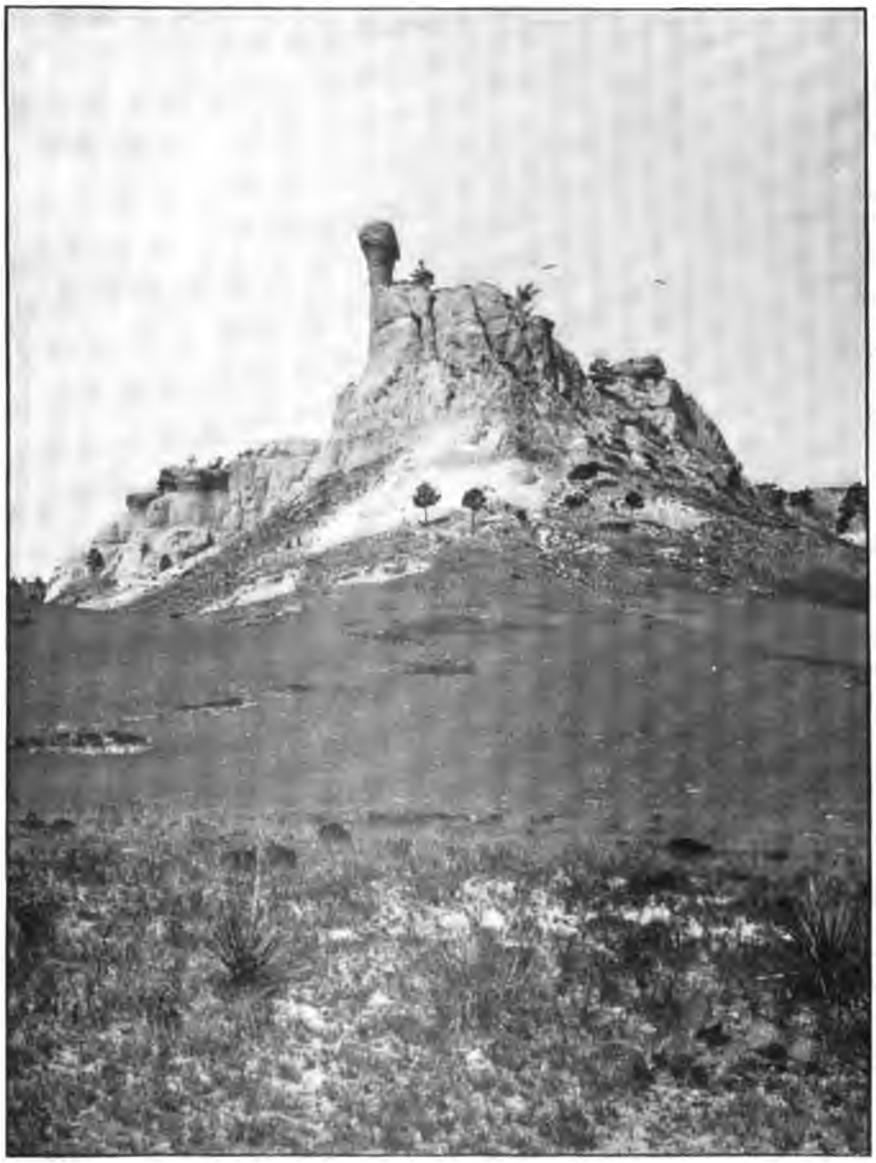
The geology of Nebraska presents broad structural features which it is necessary to outline before a clear idea can be given of the local relations in the western portion of the State. The principal formations which outcrop are extensive sheets of sands and clays of Cretaceous, Tertiary, and Pleistocene age, underlain by Carboniferous limestone, which outcrops in the southeastern counties. In the map, Pl. IX, an attempt has been made to indicate the present state of knowledge of the distribution of the principal formations. It is based on a large number of new data from personal observations. In the cross section, Pl. X, are shown the principal structural relations of the formations. The following list sets forth their order, age, and salient features:

Table of geologic formations in Nebraska.

Age.	Name.		Predominant characters.
Pleistocene	Alluvium		Sand, loam, and gravel in valleys; talus on slopes.
	Sand hills		Sand mainly in dunes, due to wind action.
	Loess		Fine sandy loam of pale brownish-buff color.
	Drift		Bowlder clays and sands of glacial origin, and sandy clays, sands, and pebble beds.
	Equus beds		Gray sands.
Neocene	Ogalalla formation (Pliocene).	Loup Fork beds.	Calcareous grit, sandy clay, and sand.
	Arikaree formation (Miocene).		Gray sand with beds of pipy concretions.
	Gering formation (Miocene)		Coarse sands, soft sandstone, and conglomerate.
Eocene (Oligocene?)	Brule clay	White River group.	Pinkish clays, hard, and more or less arenaceous.
	Chadron formation		Pale greenish-gray sandy clay.
Cretaceous	Laramie formation		Yellowish and greenish sandstone and shale.
	Pierre clay		Dark-gray clay or soft shale.
	Niobrara formation	Montana group.	Chalky limestone and shale.
	Benton shale		Dark-gray or black shale or clay.
	Dakota sandstone		Brown sandstone.
Carboniferous	Permian limestone		Buff limestones and shales.
	Cottonwood limestone		Massive limestone of light color.
	Wabaunsee formation		Limestones, shales, sandstones, and thin coal beds.



JAIL ROCK, FROM THE WEST.



SMOKESTACK ROCK, FROM THE EAST.

Showing outliers of conglomerate in Arikaree formation.

Alluvium.—Owing to the softness of the Cretaceous and Tertiary formations which constitute the surface of the greater part of Nebraska, the river valleys are wide, and they are floored to a greater or less depth with deposits of alluvial materials brought by the streams at various stages of their development. The largest alluvial areas are along the valley of Platte River, which has a width of 15 miles in the central portion of the State. Southwest of Omaha, where the river crosses the hard rocks of the Carboniferous which rise in the eastern part of the State, its valley is narrowed greatly. The valleys of Republican, Blue, Nemaha, the Loups, Elkhorn, and Niobrara rivers contain alluvial deposits of moderate width, and all the smaller valleys contain local alluvial materials to a greater or less degree. The deposits are mainly sands and loams, intermixed with pebbles in some localities, and occasionally associated with local beds of clay and accumulations of peat and diatomaceous earth.

Sand dunes.—A wide area of central Nebraska is occupied by wind-blown sands, constituting the great sand-hill district. Its area is about 24,000 square miles. The sand in this district is blown into high ridges and hills, but there are numerous intersecting valleys of various sizes which constitute a moderate proportion of the area. There are local accumulations of wind-blown sand of considerable extent along the valley of Platte River south of Kearney, along Loup River north of Grand Island, along the south slopes of the North Platte Valley west of the one hundred and third meridian, and in Chase, Perkins, and Lincoln counties.

The sands were largely derived from the Arikaree formation, but it is also probable that they are in part the remains of formations of early Pleistocene age or an extension of the Equus deposits or the loess.

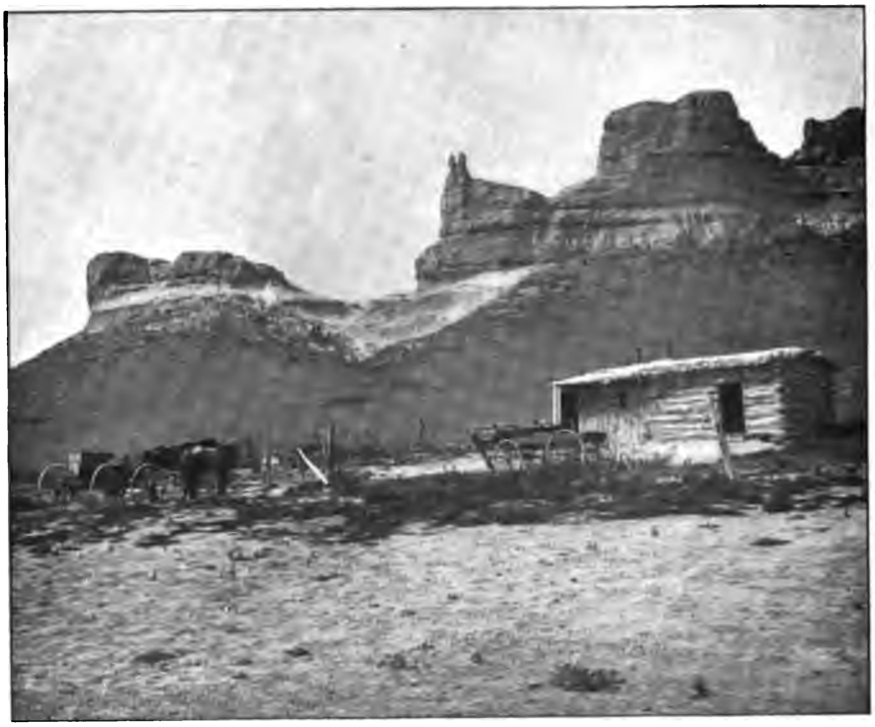
Loess.—The loess occupies more than one-third of the area of Nebraska, usually giving rise to level plains, which it underlies to a thickness of about 100 feet. The widest area is in the table-lands south of Platte River. To the northwest it is overlapped by the sand hills, but it extends far north in the eastern portion of the State and to the southwest to Dundy County. On the divides it is limited on the west by the highlands in Chase and Hayes counties, but extends farther up the valley of Republican River. The western margin in Deuel County is marked by high ridges of Tertiary formations, which constituted a shore against which the loess was deposited. The material of the loess is a fine, sandy loam, somewhat calcareous, and chiefly of a pale brownish-yellow color. Occasionally streaks of sand and old soil are found, and some portions are slightly more argillaceous than usual. The deposit is of a remarkably uniform texture, compact, but perfectly soft. Much of the water falling upon its surface is absorbed, but on steep slopes there is rapid excavation wherever a rivulet gets a fair start. In the lower part of the formation, possibly underlying it, and entirely separate, are deposits of volcanic ash, usually mixed with more or less fine sand, but often consisting almost entirely of fine shreds of volcanic glass.

The thickness of the loess is variable, but over a wide area of the central portion of the State it averages 100 feet. It has similar thickness at most points near Missouri River. In the region of drift hills about Lancaster County the thickness varies from 20 to 100 feet.

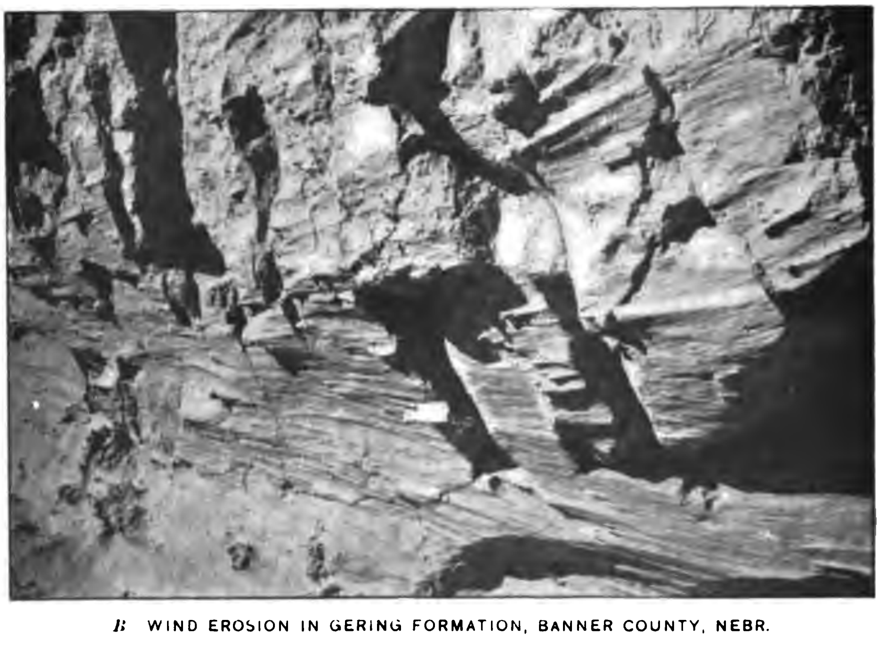
The loess is the product of a relatively long period of deposition at the close of Glacial time. In the wide area in central Nebraska it was deposited by Platte River at a stage when the river spread as a wide plexus of streams over the divide south of its present course. The deposits extend far up the slopes of the high drift hills about Lancaster County, and probably the greater portion of this area was originally entirely covered by earlier loess. Missouri River spread a wide mantle of loess across the eastern margin of the State, and in the later stages of deposition this loess was deposited in the lower, wider valleys among the drift hills.

Drift.—The glacial drift covers the greater part of Nebraska east of longitude 97° 30′. It is a product of the Kansan stage of the Glacial epoch, when a lobe of the glacier extended to Kansas River. Extending west from the glacial-drift border there is a thin sheet of sands and gravels, which is continuous under the loess to beyond the one hundred and second meridian. The greater portion of the glacial drift consists of blue and gray bowlder clays. There are locally included sand beds, and in some localities extensive deposits of bowlders. The pink Sioux quartzite, often in very large masses, is a conspicuous feature of the drift, but there are many other rocks associated with it. Wide areas of clay surfaces with only a few scattered bowlders occur, and there are other areas of light sandy clays, particularly on the higher level lands, which appear to be loess merging into the glacial drift. The drift is thick in Lancaster and Gage counties. It thins rapidly toward Missouri River, where it is usually represented by a thin layer of gravel underlying the thick mantle of loess. The thin drift sheet, which extends far west from the glacial-drift margin under the loess, is usually sand or sandy clay, commonly of pinkish color. To the north it is often represented by coarse sand, and to the west it merges into a gravel bed. Pebbles of a great variety of rocks, apparently mainly of Rocky Mountain origin, occur throughout. The westernmost extension of this deposit observed was in the table-land north of Big Spring, in Deuel County, where it is represented by a bed of gravel 20 feet thick underlying 100 feet of loess.

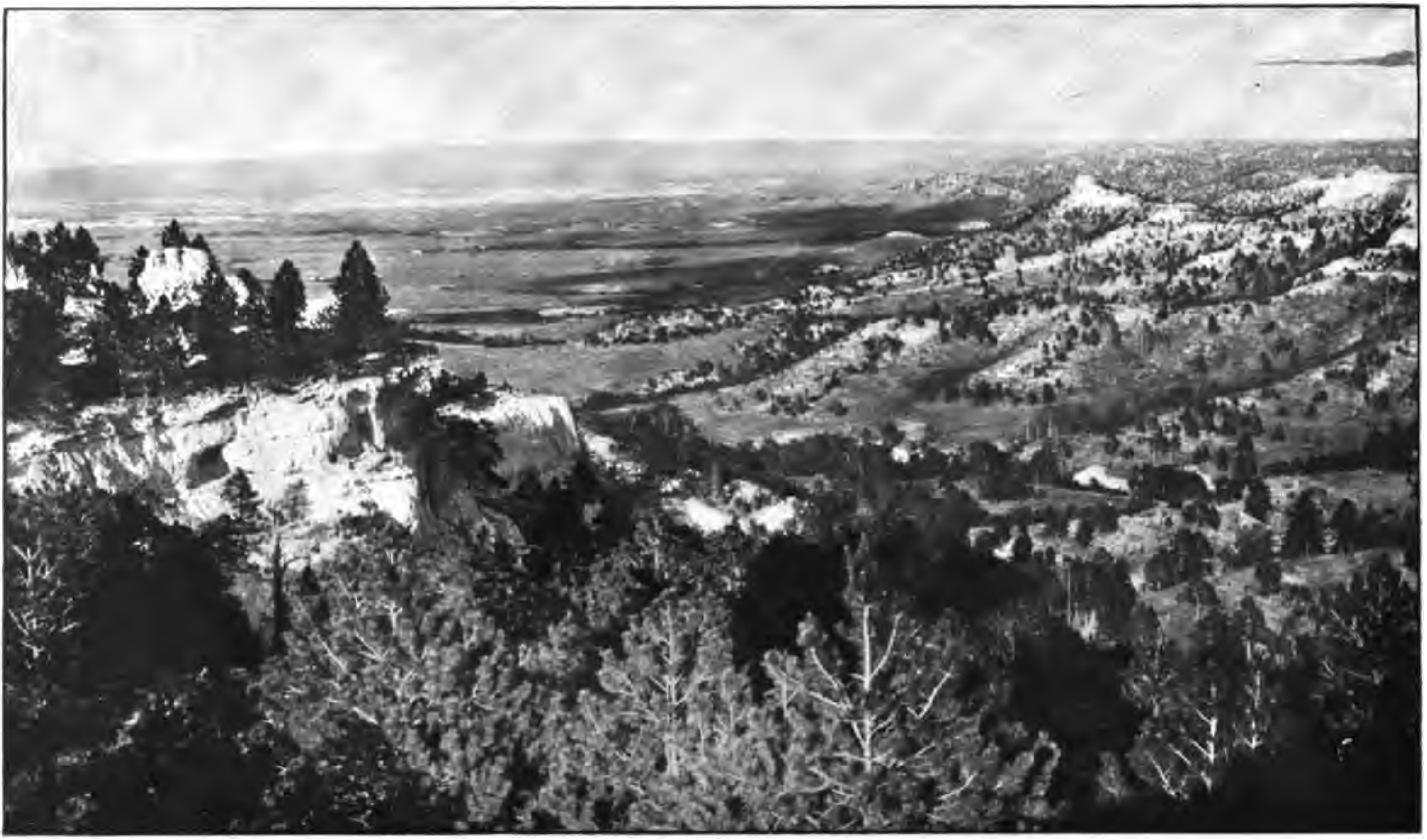
Ogalalla formation.—Extending from Kansas and Colorado far into Nebraska there is a calcareous formation of late Tertiary age to which I wish to apply the distinctive name *Ogalalla formation.* It is a portion, if not the whole, of the deposit which in Kansas and southward has been called the "Mortar beds," "Tertiary grit," and other names. It has been regarded as a portion of the Loup Fork



A. "TWIN SISTERS," BANNER COUNTY, NEBR.



B. WIND EROSION IN GERING FORMATION, BANNER COUNTY, NEBR.



NORTH FACE OF PINE RIDGE, LOOKING NORTHEAST OVER HAT CREEK BASIN.

Showing cliffs of Arikaree formation. Badlands in Brule clay in the distance. (From photograph by E. H. Barbour, University of Nebraska.)

formation. It is extensively developed in the western part of Nebraska, in the region about Lodgepole Creek and in the area between Platte River and the Kansas line west of the ninety-ninth meridian. It thins out in Banner County and in the central part of Cheyenne County, giving place to the northwest to an underlying member of the Loup Fork series. It crosses North Platte River in the western part of Deuel County, but its limits in the central and northern portions of the State have not been ascertained. It appears to underlie a portion at least of the great sand-hill district. In its typical development the Ogalalla formation is a calcareous grit or soft limestone containing a greater or less amount of interbedded and intermixed clay and sand, with pebbles of various kinds sprinkled through it locally, and a basal bed of conglomerate at many localities. In places it merges into a light-colored sandy clay, generally containing much carbonate of lime in streaks or nodules. The pebbles it contains comprise many crystalline rocks, which appear to have come from the Rocky Mountains. These pebbles accumulate on the disintegrating surfaces of the Ogalalla formation, and they appear to have contributed largely to the gravel bed underlying the loess to the east.

Arikaree formation.—In the western portion of Nebraska there is found underlying the Ogalalla formation a series of sands of gray color everywhere characterized by layers of dark-gray concretions which often have tubular form. This formation enters the State from Wyoming, and has been found to thin out under the Ogalalla formation in the eastern portion of Banner County. It has a thickness of 400 feet in Scotts Bluff County and of 500 feet in Sioux and Dawes counties, the amount increasing as the Arikaree displaces the Ogalalla formation northward. It is extensively exposed along Niobrara River, apparently to the east of Valentine, and it is seen occasionally along the western edge of the sand-hill district, but it has not yet been distinctly recognized in the region drained by the Loup Forks or along Platte River east of Cheyenne County. In its upper portion are beds containing the large *Dæmonelix* of Barbour. The name Arikaree has been applied to the deposit for the reason that the Arikaree Indians were at one time identified with the area in which it is most largely developed. It is distinctly separated from the Ogalalla formation by erosional unconformity and overlap, which is clearly illustrated in the western portion of the State. The formation includes a large amount of volcanic ash, as a general admixture in its sediments as well as in beds of considerable extent and thickness. It also contains a number of channels filled with conglomerate, which will be described in detail later. (See p. 28.)

Gering formation.—This formation, like the Arikaree and Ogalalla formations, was differentiated in the summer of 1897. It consists of laminated, massive, and cross-bedded, light-gray, mainly coarse sands and soft sandstone at the base of the Arikaree formation. The character of the deposits and the abrupt change from the typical Arikaree formation have afforded a basis for the discrimination of this formation. It has been found in Scotts Bluff, Banner, Cheyenne, Sioux, and Dawes counties, and locally attains a thickness of 200 feet. It often comprises two members, more or less distinctly separated by unconformity, and it lies unconformably on the Brule clay. The materials are sands, which vary from coarse to fine, and they are often sufficiently lithified to be classed as soft sandstone. At the base there is usually more or less conglomerate of local origin. In some districts the formation thins out and appears to be entirely absent, but possibly in this case it has simply lost its distinctive characteristics, so that it would be overlooked as the lower portion of the Arikaree formation. In some cases where the formation is thought to be absent there is seen to be unconformity below the Arikaree beds.

Brule clay.—The White River beds in their extension from South Dakota into Nebraska present some differences in stratigraphic range and relations. They expand considerably and include, at their top, beds which appear not to be represented in the typical regions. Accordingly, to afford distinct definitions for the members in Nebraska, I have introduced the designation *Brule clay*, and separated the underlying Titanotherium beds as the *Chadron formation.*

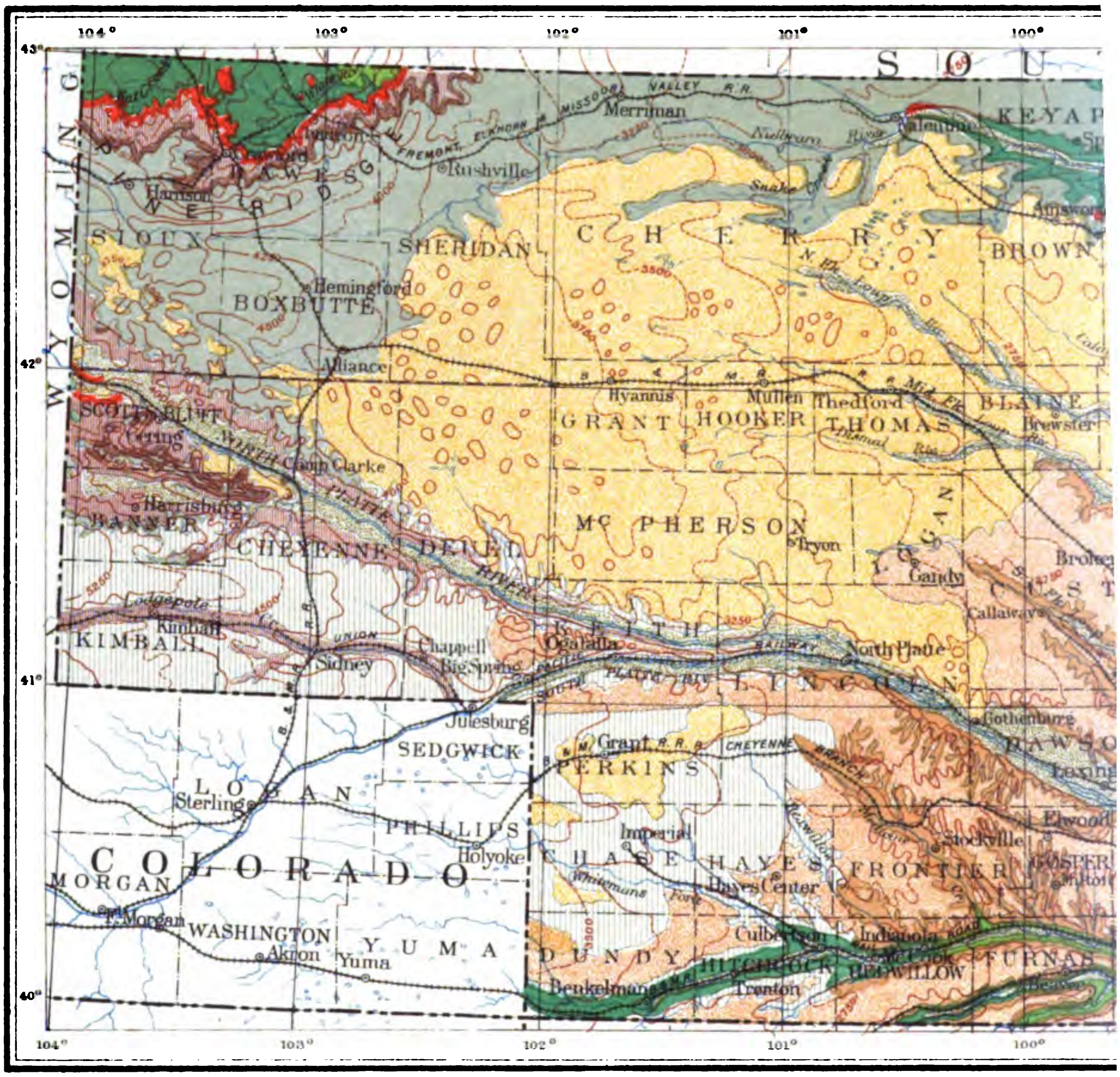
The Brule clay consists mainly of a hard, sandy clay, of pale-pink color. Its thickness averages about 600 feet in the vicinity of the Wyoming line, but the amount diminishes greatly eastward. In the vicinity of the one hundred and third meridian in the northwest corner of the State it has a thickness of 320 feet. The formation has not been recognized east of longitude 101° 30′, where it appears to sink beneath the surface in the Platte Valley. It extends far to the northeast in South Dakota.

Chadron formation.—Lying under the Brule clays there is a thin sheet of light-greenish, sandy clay, the basal member of the White River series, known as the "Titanotherium beds." Its outcrops extend in a narrow zone across the northern portion of the State, and it is apparently exposed along North Platte River near the Wyoming line. It is known to underlie portions of Colorado and South Dakota, but it appears not to extend far eastward in southern Nebraska, for it is absent along Republican River. It is reported that *Titanotherium* remains were obtained near Longpine, but nothing has been learned of the relation and extent of the beds in that locality.

Laramie formation.—The Laramie formation extends under the southwestern corner of Nebraska, but probably to no great distance. Its only exposures are along the State line on Horse Creek west of Caldwell and in another small area a few miles southwest of that place, where it rises in a low mound under the Brule clay. The rocks are yellowish and greenish sandstones and clay.

Pierre clay.—All of Nebraska west of the ninety-eighth meridian is underlain by the Pierre clay. Its surface outcrops are in the lower portion of the Niobrara Valley,

U.S. GEOLOGICAL SURVEY



PRELIMINARY GEOLOGIC MAP C

Scal

25 0 25 50

$\frac{1}{2,500\,0}$

PLEISTOCENE

▨ **ALLUVIUM**
(Only the wider areas are shown)

☐ **SAND HILL DISTRICTS**
(To the southeast the sand hills lie on unclassified Tertiary formations which outcrop in some of the valleys)

☐ **LOESS**
(Underlain by drift which is of glacial origin east of the line Some higher portions of glacial drift area appear to be bare of loess)

☐ **OGALALLA FORMATION**

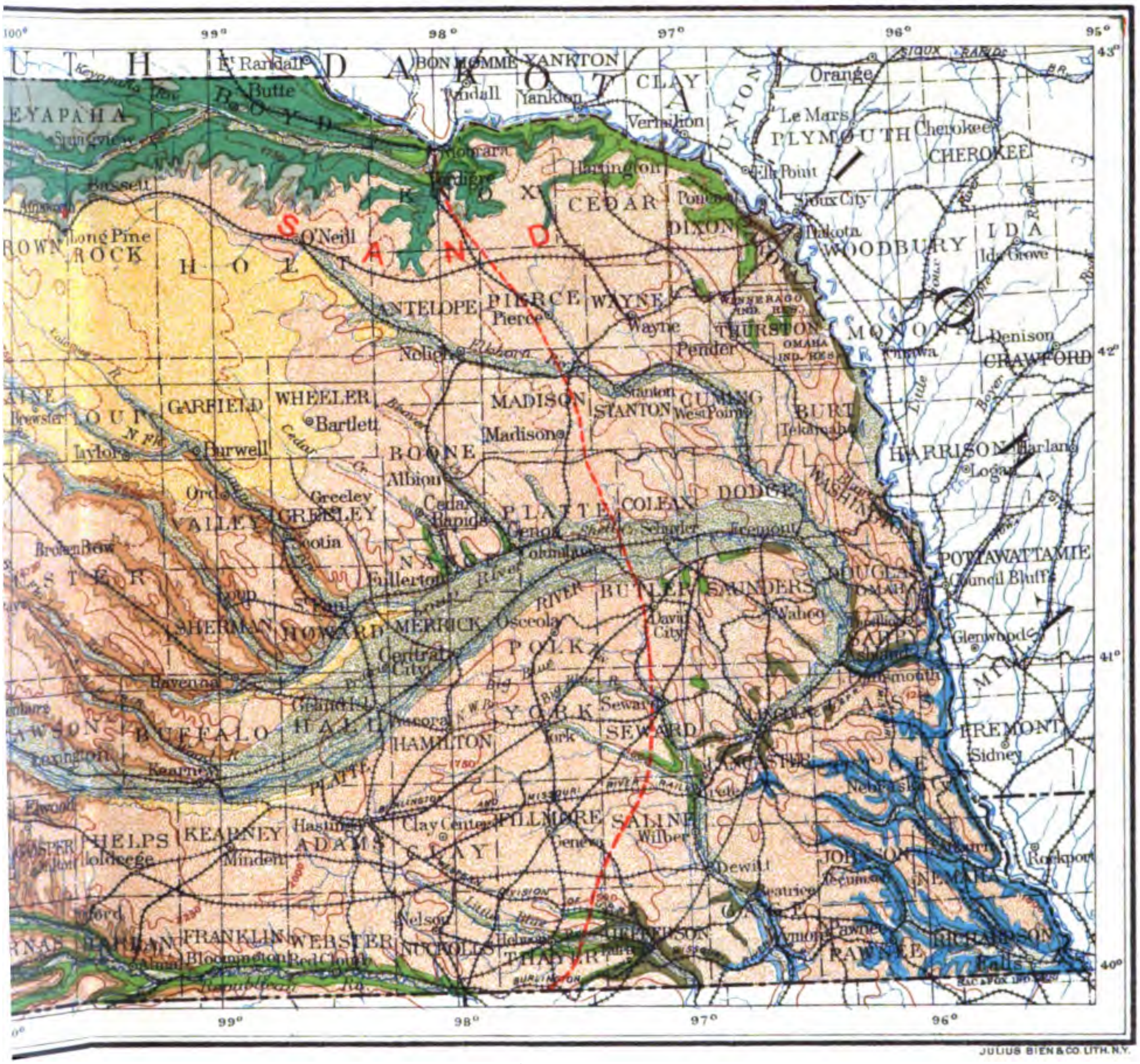
☐ **UNCLASSIFIED TERTIARY**
(Mainly Arikaree and Ogalalla formations or "Loup Fork")

CRETACEOUS

▨ **LARAMIE FORMATION**

■ **PIERRE CLAY**

☐ **BENTON ANI**
FORMA



AP OF NEBRASKA, BY N. H. DARTON

Scale $\frac{1}{2\,500\,000}$

50 75 100 125 miles

TERTIARY

MATION

▭ **ARIKAREE FORMATION** (Overlain by Equus beds in places)

■ **GERING FORMATION**

▨ **BRULE CLAY**

■ **CHADRON FORMATION** (Titanotherium beds)

S

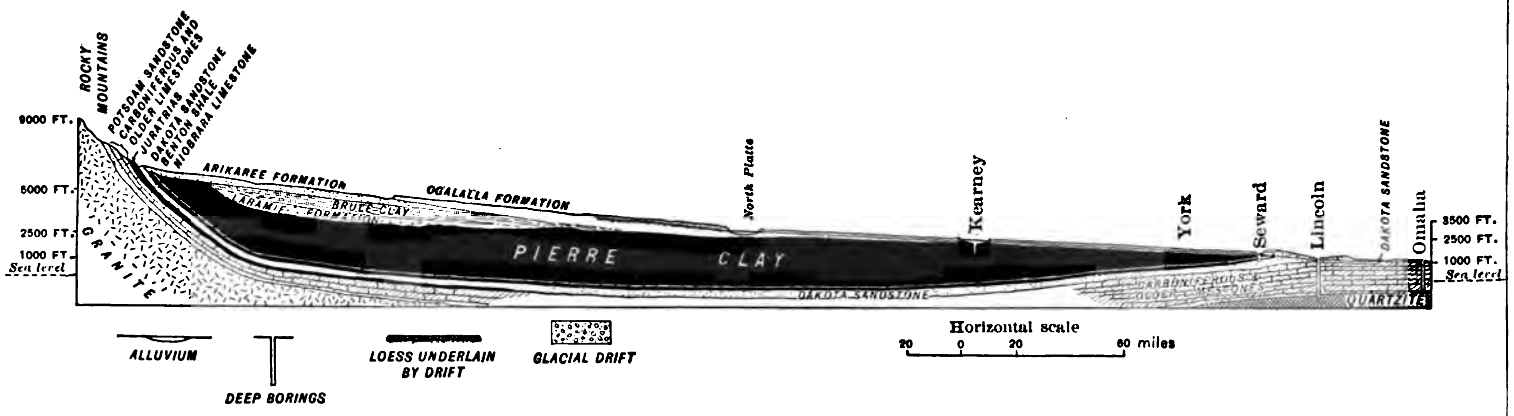
▭ ON AND NIOBRARA FORMATIONS

■ **DAKOTA SANDSTONE**

CARBONIFEROUS

▭ **PERMIAN SERIES**

■ **PENNSYLVANIAN SERIES**



WANZ, N.Y.

CROSS SECTION FROM ROCKY MOUNTAINS TO OMAHA, ACROSS NEBRASKA.

the Republican Valley, and the extreme northwest corner of the State, but it is probable that careful search will reveal outcrops in the valley of the Platte River in the vicinity of the ninety-sixth meridian. The formation is a thick mass of dark-gray or bluish clay or soft shale. Its thickness is probably at least 2,000 feet in the central-western portion of the State.

Niobrara and Benton formations.—Underlying the Pierre clay there is a series of chalky limestones known as the Niobrara formation and shales known as the Benton formation. They have a thickness of about 450 feet to the east, but thicken to the west. At the base there are about 200 feet of dark shales, overlain by slabby limestones of the Greenhorn formation containing *Inoceramus*, which are followed by a series of shales with few thin sandy layers, and at the top the Niobrara formation with its chalky deposits characterized by thin hard beds filled with *Ostrea congesta.* The formations cross the eastern portion of the State, and underlie all of the area west of the vicinity of the ninety-seventh meridian, but they are so deeply buried under drift and loess that outcrops are rarely visible. The most extensive exposures are along Missouri River, extending from near the ninety-seventh to the ninety-ninth meridian, and along the Republican Valley from Alma to near Superior. The formations are exposed at intervals across the eastern portion of the State in each of the larger valleys and some of the branches. The more notable of these small outcrops are at Genoa, north of Germantown, near Crete, at Pleasant Hill, and in Beaver Creek north of Dorchester. There is an exposure of dark shales under some ledges of Greenhorn limestone in Big Blue River at Milford, which are Benton. During the summer of 1897 upper Benton and Niobrara beds were discovered rising in a prominent anticline along White River in the vicinity of Beaver and Alkali creeks, in the northwest portion of the State.

Dakota sandstone.—The Dakota sandstone underlies nearly all of Nebraska, and outcrops in a narrow belt extending from Missouri River to the vicinity of the ninety-seventh meridian. It is gray or brown sandstone, containing streaks of clay of greater or less size, and its aggregate thickness is about 400 feet, including a basal series of Lower Cretaceous sandstone. Its surface passes under the Benton shales, and, owing to the low westerly dip and the gradual increase in altitude of the State to the west, the Dakota sandstone is soon deeply buried. In the central portion of the State it probably lies over 2,500 feet below the surface. In its outcrop area it is heavily covered by drift and loess, but there are numerous exposures in the banks along Missouri River in Dakota County—which was the type locality of the formation—along Platte River from Ashland nearly to Plattsmouth, along the valley of Salt Creek and its branches, at Beatrice, and in the valley of Little Blue River in Jefferson County. The formation carries the great artesian-water supplies, which are so extensively developed by wells in eastern South Dakota and on lowlands in Knox, Cedar, and Boyd counties, Nebraska.

Carboniferous formations.—The Carboniferous limestones, shales, and sandstones underlie all of Nebraska, rising to the north and northwest about the Black Hills and on the slopes of the Rocky Mountains, as shown in Pl. X and fig. 21, on page 46. The outcrops in eastern Nebraska are in Douglas, Sarpy, Cass, Lancaster, Otoe, Gage, Johnson, Pawnee, Nemaha, and Richardson counties. The rocks are hard and would give rise to more prominent features in this region if it were not for the heavy covering of glacial drift and loess. As it is, the exposures constitute cliffs along Platte River from Ashland to Plattsmouth, and thence at intervals along Missouri River to the southeast corner of the State, and occur in scattered outcrops along the valleys of Big Blue, Nemaha, and Little Nemaha rivers and Weeping Water, Turkey, and Southeast Salt creeks and their branches.

The rocks of the Carboniferous period in this region comprise formations of Permian and Upper Coal Measure or Pennsylvanian age. The Permian outcrops are probably restricted to the valley of Big Blue River from Beatrice southward. The rocks are mainly magnesian limestones of light color with interbedded shales. They are extensively exposed south of Beatrice, at Rockford, Blue Springs, Wymore, and Holmesville. The other Carboniferous members appear to comprise the Cottonwood and Wabaunsee formations of the Kansas geologists. They consist of limestones, shales, and sandstones, which contain thin coal beds in some localities. Professor Prosser has made a preliminary examination of the Carboniferous of Nebraska, and identifies as Wabaunsee the exposures about Peru, Aspinwall, Nebraska City, Auburn, Tecumseh, Dunbar, Nehawka, Weeping Water, and in the long section along Platte River near Louisville. The Cottonwood limestone, a massive bed full of *Fusulina*, was recognized west of Auburn about Glen Rock and Johnson, and the same beds extend over the higher lands of western Richardson and Pawnee counties.[a] In the deep borings which have been made at various points in the southeastern corner of the State it has been found that the Carboniferous formations have a total thickness of about 1,200 feet, of which about 200 feet are Permian. In the deep well at Lincoln the lower limestones were found to be 835 feet thick and underlain by 800 feet of magnesian limestones of undetermined, but probably in part Devonian, age; these, in turn, by limestone apparently of the Trenton formation, extending from 1,813 to 1,947 feet; a supposed representative of the St. Peter sandstone, having a thickness of 61 feet; 113 feet of magnesian limestones, supposed to be the Magnesian limestone of the Mississippi Valley; and a red sandstone, extending from 2,121 to 2,192 feet, thought to be Cambrian. This was found to lie on a red quartzite—penetrated for 270 feet—supposed to be an extension of the Sioux Falls quartzite of Algonkian age, which is underlain by granite rocks northward.

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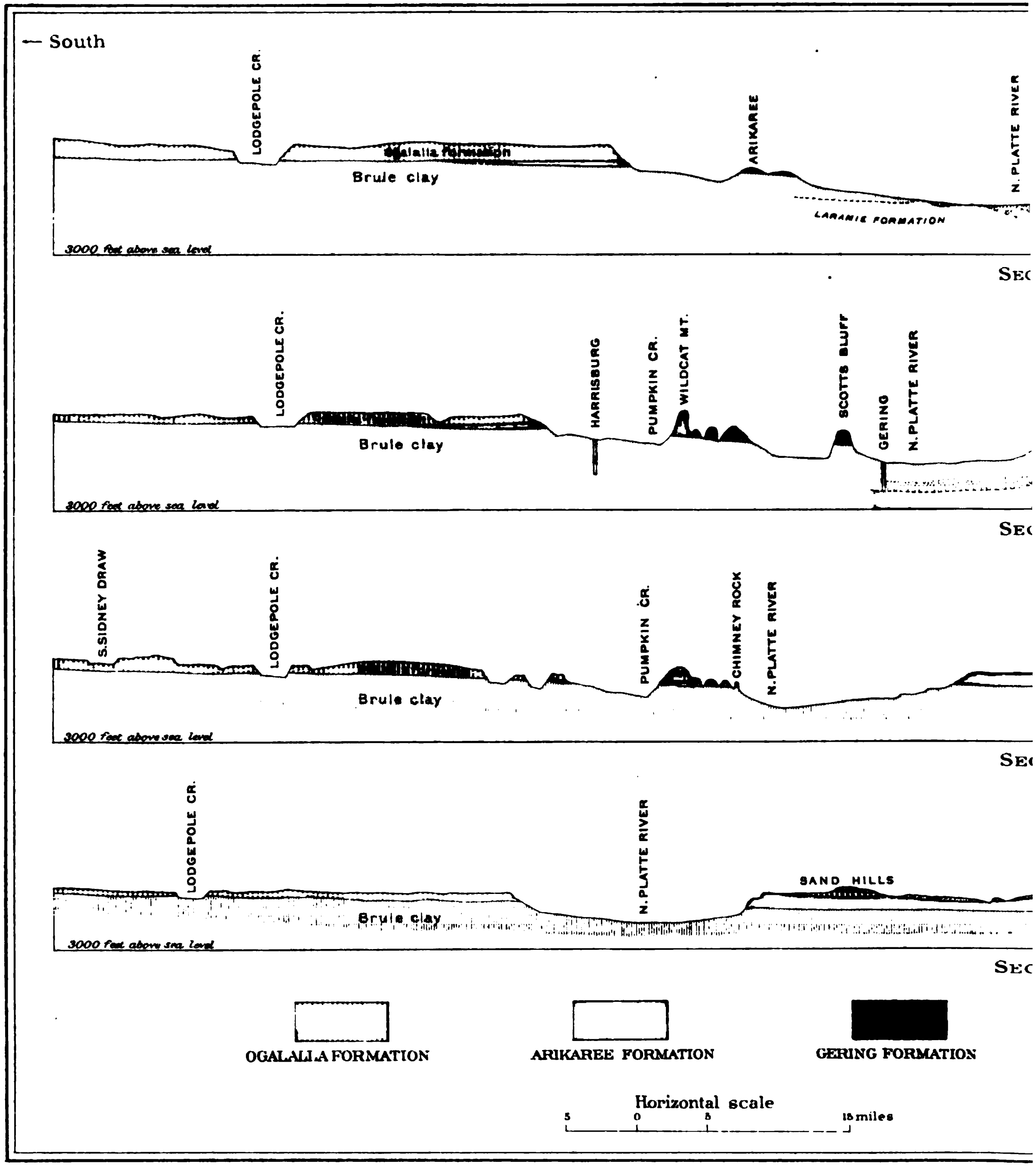
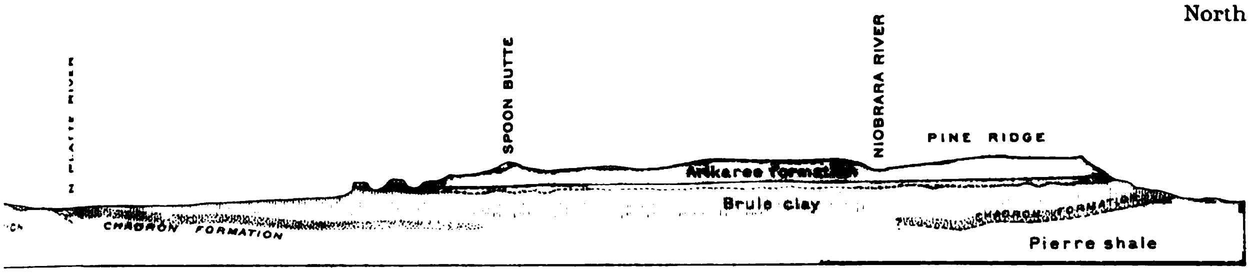
[a] Jour. Geol., vol. 5, 1897, pp. 1-16.



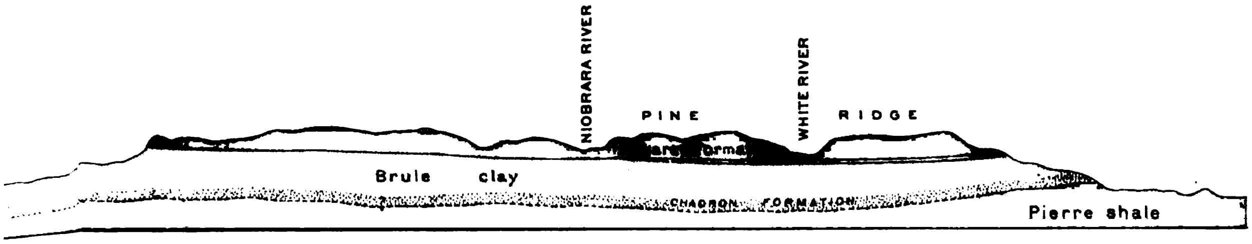
GEOLOGIC SECTIONS ACROSS NEBRASKA

ALONG THE LINES 1, 2

BY N. H. DA



SECTION 1.



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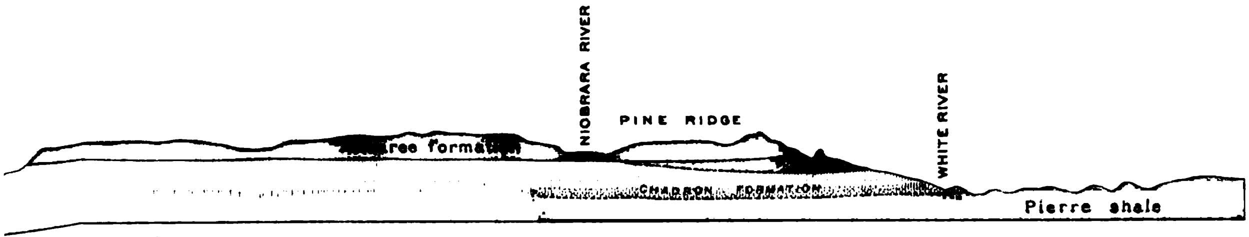

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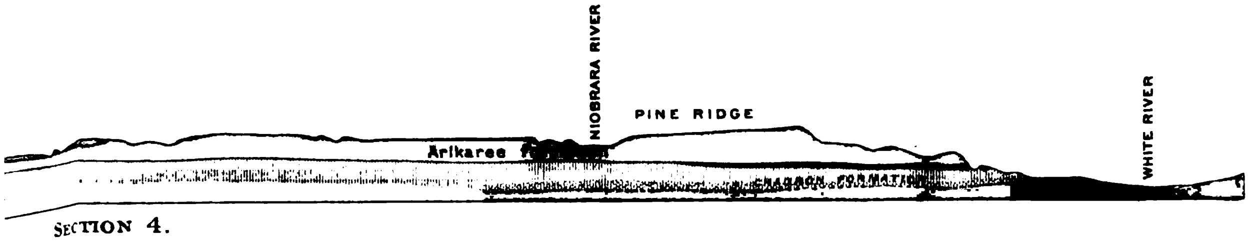


SECTION 4.

▮ ATION

■ BRULE CLAY

▭ PIERRE SHALE

▭ LARAMIE FORMATION

Vertical scale

2500 0 2500 feet

JULIUS BIEN & CO LITH N Y

ASKA WEST OF THE 103D MERIDIAN, LOOKING WEST
ES 1, 2, 3, AND 4, ON PLATE XI.
N. H. DARTON, 1898

There are possibly two other formations underlying portions of Nebraska but not reaching the surface. To the northwest there is doubtless an extension of the Juratrias red sandstones and greenish sands and clays which are exposed so conspicuously about the margin of the Black Hills, only 55 miles distant from the northwest corner of the State. They lie between the Carboniferous limestone and the Dakota sandstone, as shown in the sections, Pl. X and fig. 21, on page 46. They are absent in the eastern portion of the State, but in part are extensively developed in Kansas.

The other formation which may extend into Nebraska is the Laramie sandstone, which lies between the Pierre shale and the Tertiary formations in northeast Colorado. It would not be surprising if this formation should be found to underlie a portion of extreme western Nebraska, but it is known to be absent in the Republican Valley as far west as Dundy County, and in the region north of Pine Ridge, in Sioux and Dawes counties.

GEOLOGY OF THE REGION WEST OF THE ONE HUNDRED AND THIRD MERIDIAN.

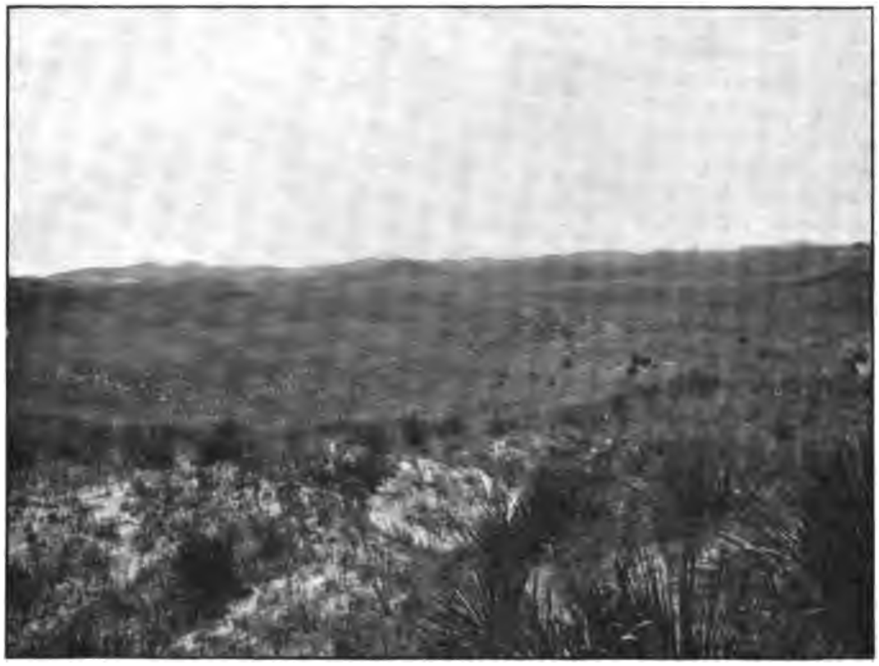
GENERAL RELATIONS.

The formations of this region comprise alluvium and dune sands and Ogalalla, Arikaree, Gering, Brule, and Chadron formations, lying on a thick mass of Pierre clay and the northeastern edge of the Laramie formation. The loess and drift are not present. The distribution of these formations, except the alluvium, is shown on the geologic map, Pl. XI. Their structural relations are shown in the series of cross sections, Pl. XII. The older formations underlying the Pierre shale do not reach the surface nearer than the southern slopes of the Black Hills, where, as shown in fig. 21, they rise in regular succession.

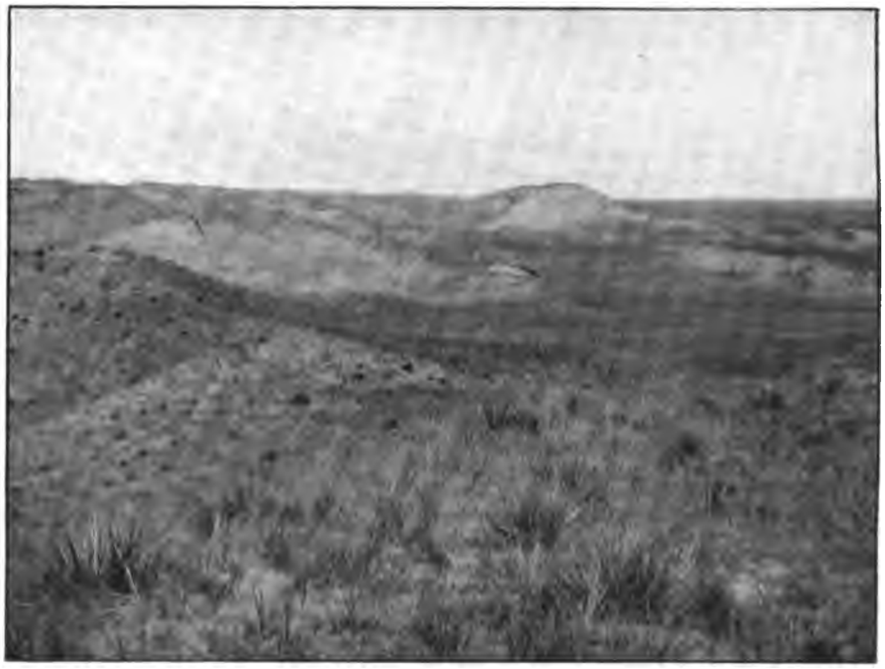
The relations of the formations, as shown in Pls. XI and XII, are relatively simple. There is a broad, thick sheet of Brule clay, underlain by a thin layer of Chadron formation, lying on the irregular surface of the Pierre clay, which outcrops in the region north of the foot of Pine Ridge. The Gering formation is a thin sheet of coarse sand and soft sandstone which lies on the Brule clay, mainly in channels. It appears to outcrop continuously along the northern front of Pine Ridge, about halfway up the slope; it has been recognized at one point on the north slope to the valley of North Platte River. It is extensively developed in wide channels in the ridge lying next south, but it is absent in the table-land south of Pumpkinseed Creek, except probably in a small outlier exposed far up the valley of Lawrence Fork. The Arikaree formation, consisting of fine sands with dark-gray pipy concretions, constitutes the crest of Pine Ridge and the table-land extending north of the Platte Valley. It also heavily caps the ridge lying between the valleys of the Platte and the Pumpkinseed, but it thins rapidly to the south and east in the high table-land south of the Pumpkinseed Valley, and dies out east of the mouth of Lawrence Fork. The Ogalalla formation, consisting mainly of light-colored pebbly sands cemented by carbonate of lime, covers the table-land south of the Pumpkinseed Valley, lying on the Brule clay to the east and on a thickening wedge of the Arikaree formation to the west. Outlying masses cap certain high points on the ridge north of the Pumpkinseed Valley, and it may possibly be present on the higher portions of the table-land north of Platte River, together with outliers of the Equus beds. The larger sand-hill areas are on the table-land north of the valley of Platte River, but smaller areas are found in both Platte and Pumpkinseed valleys. Alluvium, which is not represented on the map and sections, floors portions of the valleys and merges upward into wash and local talus on the slopes of the hills.

ALLUVIAL FORMATIONS.

On the lower slopes adjacent to North Platte River and along the other streams of the region there has been deposited a greater or less thickness of materials brought by the streams from the higher lands. In the valley of Platte River there is a wide zone of bottom lands bordering each side of the river, on which is found a mantle of alluvium, several feet thick, lying on the older formations in which the river valley was cut. The materials consist mainly of sandy loams with occasional coarse constituents. On the adjoining terraces above is found a mantle of sand and gravel, deposited when the river was much higher than it is now. The gravels contain many rocks from the Rocky Mountains, comprising granites of various kinds, quartzites, chalcedonic vein stones, often of considerable beauty, and a small variety of eruptive rocks. The materials vary in size from coarse sand to moderately large bowlders. The coarser deposits give rise to long narrow ridges or lines of knobs, while the materials of intermediate coarseness cover terraces, which in some cases extend back from the river bottom for several miles. It is claimed that small showings of gold have been panned from these formations at several localities. In the valleys of Lodgepole and Pumpkinseed creeks and White River the alluvial materials are mainly in narrow belts of bottom lands, and consist chiefly of local materials. In the valley of Pumpkinseed Creek, however, there are at higher levels extensive deposits of coarser gravels containing rocks from the Rocky Mountains similar to those along Platte River. It is probable that this river at one time sent a branch stream through the wide depression now occupied by Pumpkinseed Creek and spread the gravel on the high terraces. At that time the ridge lying north of Pumpkinseed Creek was an island in the midst of a wider Platte River, but the valleys were not so deep as they are now. Nearly every stream flowing out of the high lands has brought down more or less alluvial material in the shape of sand or local gravel, which merges into the alluvial deposits of the larger valleys. There



A.



B.

TYPICAL SANDHILLS IN WESTERN CHEYENNE COUNTY, NEBR.

A, Leeward side, looking west; *B*, windward side, looking southeast, showing blowouts.

is also on nearly all of the slopes adjoining the valleys a talus or wash of sand and clays from above, which often covers the underlying formations to considerable thickness.

None of the alluvial formations have been shown on the geologic map, Pl. XI, because some of their relations are too intricate for accurate representation on a small scale.

SAND DUNES.

The sand hills are a distinct geologic formation in this region, in part contemporaneous with the alluvial deposits along the bottoms of river valleys. They are in process of formation and modification by the strong winds, and are in a measure still moving to the southeast. Two typical views of the sand-hill region are reproduced in Pl. XIII. The sand now constituting the sand hills was derived mainly from the Arikaree formation, having been carried over the plains by the wind and accumulated about the obstructions. The manner in which the sand is blown away is well illustrated in Pl. XVIII, *A*. The sand-dune areas in the North Platte Valley no doubt derived a portion of their material from the sand banks and other alluvium of the river which have been blown by the wind and lodged against obstructions. This is particularly well illustrated in the area which abuts against Chimney Rock. The small areas about Caldwell and Dorrington and at other points in the Pumpkinseed Valley are probably of similar origin, except in a few cases where local sources have supplied the materials.

OGALALLA FORMATION.

The Ogalalla formation is the uppermost division of the Tertiary deposits of this region. It constitutes the high table-lands on both sides of the Lodgepole Valley, and caps the several small high summits about Wildcat Mountain, northwest of Ashford. As before explained, it is in the main the extension of the "Tertiary grit," "Magnesia," or "Mortar beds" of the Kansas geologists. It consists of an impure calcareous grit, or sand cemented with carbonate of lime. At its base there are often beds of conglomerate, with pebbles consisting mainly of gray sandstone or limestone. Throughout its mass there are scattered pebbles of crystalline rocks from the Rocky Mountains, streaks of pebbly sand, and thin ledges of sandstone. The harder calcareous beds are of white or cream color, and outcrop in irregular cliffs along the slopes of depressions. Some softer intercalated beds of sandy character are of light-pinkish color. The formation has a relatively level surface, which constitutes the floor of the high table-land of Kimball County and the southern portion of Banner and Cheyenne counties. When the rock disintegrates on the surface a greater or less accumulation of sand and scattered pebbles remains, often constituting a soil of greater or less thickness. This soil, when irrigated, usually proves to be very productive. The general thickness of the Ogalalla formation varies from 150 to 300 feet, the greater amount being along the Wyoming line, in the northwest corner of Kimball County. As the surface has been more or less eroded, the original thickness is unknown. The altitude of its base is 4,100 feet south of Lapeer, 5,200 feet west of Harrisburg, 4,300 feet near Bronson, 5,100 feet west of Bushnell, and 5,000 feet on Wildcat Mountain. The wider relations of the Ogalalla formation to the older Tertiary formations are shown in the cross sections in Pl. XII. In these sections it will be seen that in Lodgepole Valley the Ogalalla formation lies directly on the Brule clay; along the south side of the Pumpkinseed Valley it lies on the Brule clay to the east, and then on the Arikaree formation, which comes in and gradually thickens to the west. An exposure of its basal conglomerate is shown in Pl. XIV. At this exposure the Arikaree beds are thin, as shown in Pl. XV, *C*. It is everywhere clearly separated below by erosional unconformity, and its base is usually a shore deposit of pebbles of gray siliceous and calcareous rocks. In the outliers about Wildcat Mountain the thickness is about 50 feet, and the formation lies on a thick mass of Arikaree formation, from which the basal conglomerate is very distinctly separated by an unconformity. The relations in this vicinity are shown in fig. 1.

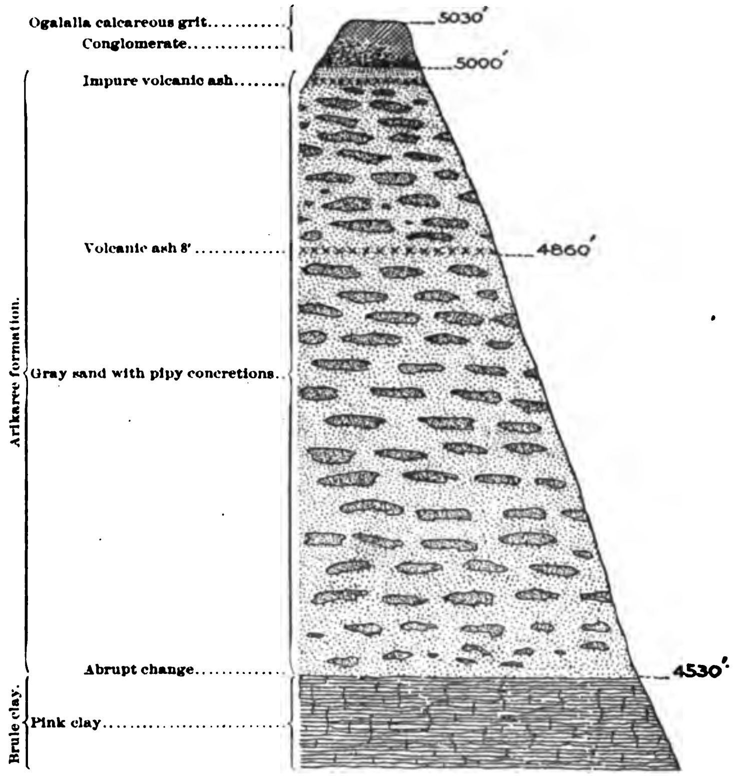
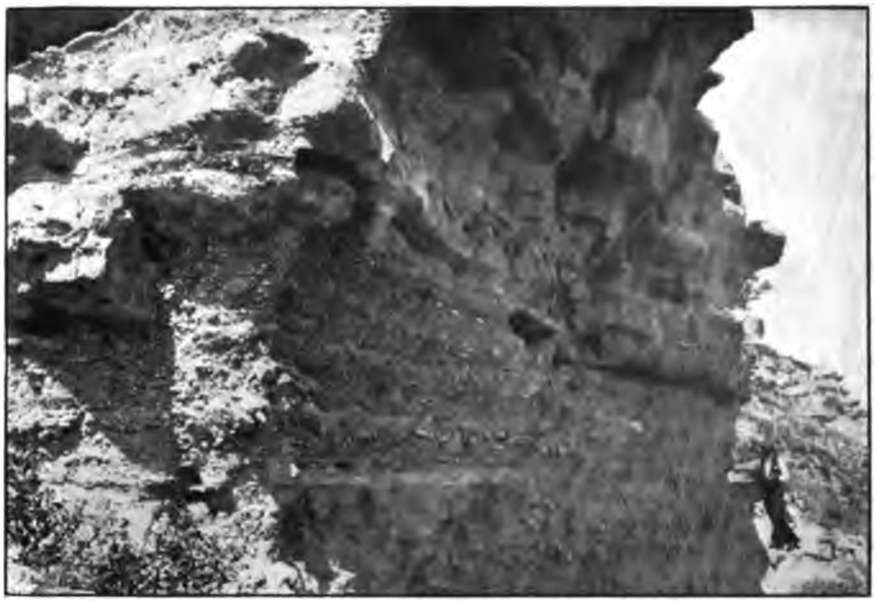
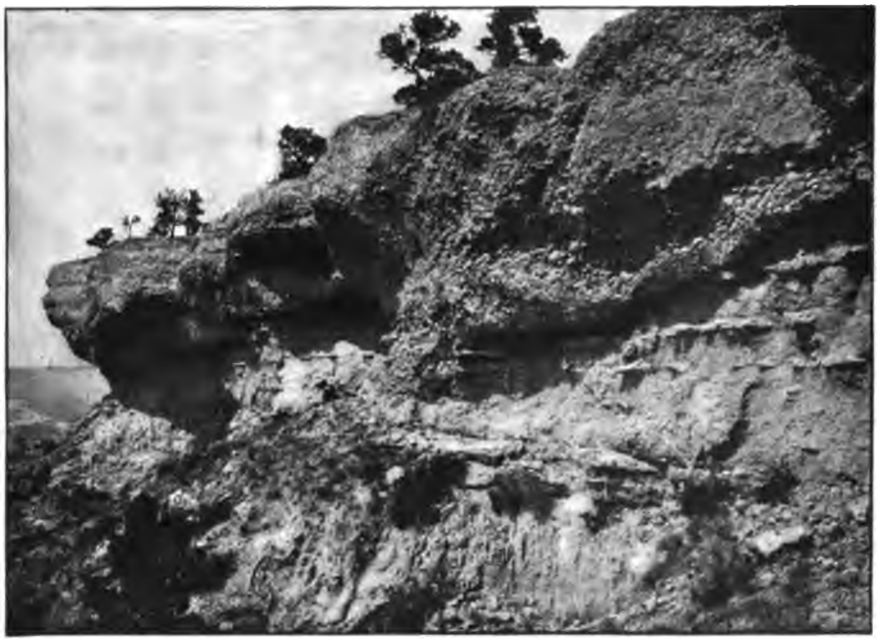


FIG. 1.—Columnar section of formations exposed in Wildcat Mountain and vicinity, Banner County, Nebr.

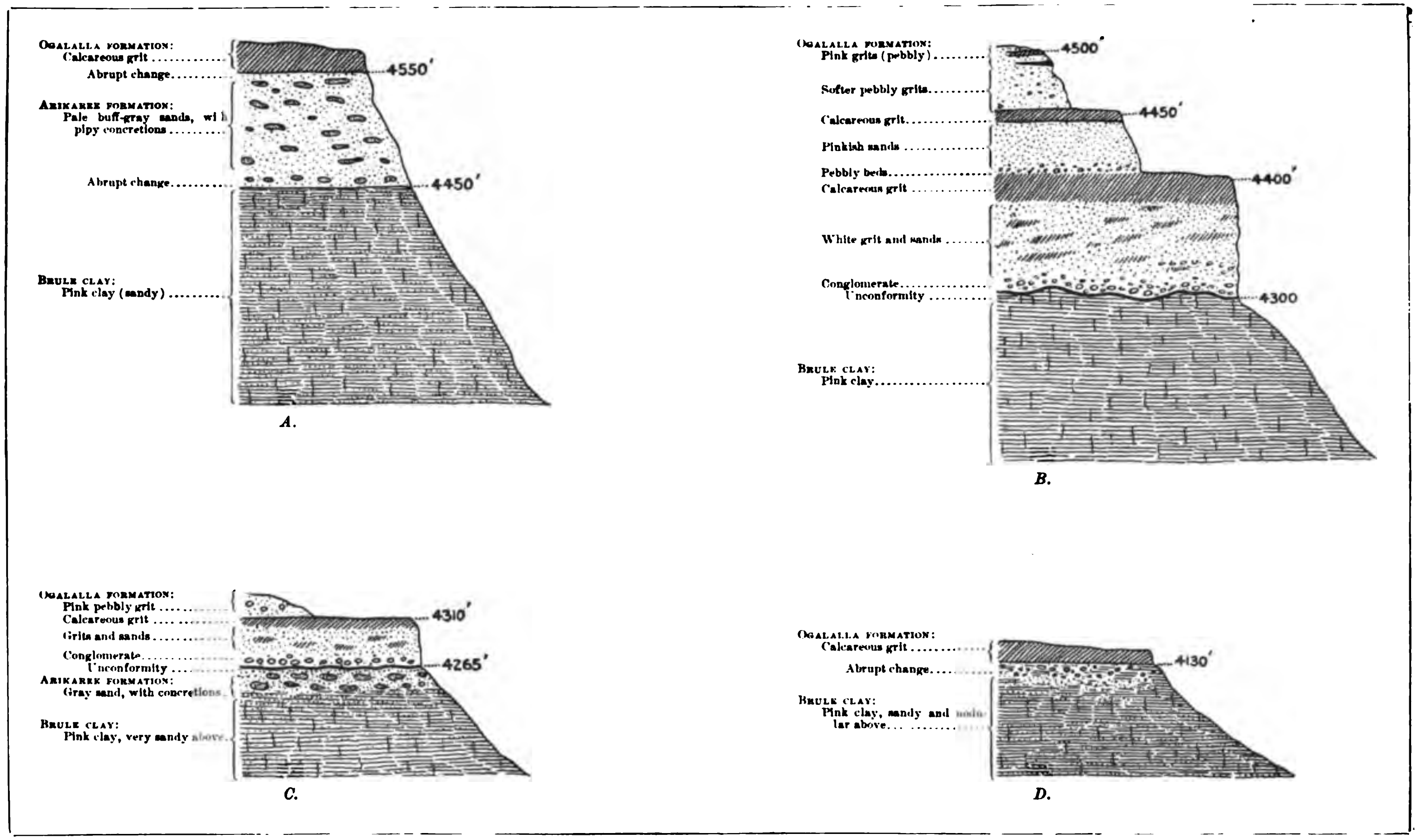


A. CONGLOMERATE AT BASE OF OGALALLA FORMATION 5 MILES SOUTH-SOUTHEAST OF REDINGTON, CHEYENNE COUNTY, NEBR.

The conglomerate lies on Arikaree formation.



B. CONGLOMERATE IN ARIKAREE FORMATION 3 MILES DUE SOUTH OF LARISSA, SCOTTS BLUFF COUNTY, NEBR.; LOOKING NORTHWEST.



SECTIONS OF EXPOSURES OF ARIKAREE AND OGALALLA FORMATIONS AT AND NEAR LANGS POINT, NEBR.

A, 8 miles west of Langs Point; *B*, at Langs Point; *C*, 5 miles east of Langs Point; *D*, 10 miles east of Langs Point.

Some typical sections illustrating the relations of the formations are given in Pl. XV. There may possibly be a small area of Ogalalla formation to the east on portions of the table-land north of North Platte River, but it was not distinguished. A few vertebrate remains were collected in this formation, and it was found to contain the smaller *Dæmonelix* forms in considerable abundance in some localities.

ARIKAREE FORMATION.

The Arikaree formation attains its greatest development in Pine Ridge, where it presents a thickness of about 500 feet. It constitutes a wide area of table-land extending from Pine Ridge to the northern margin of the valley of North Platte River. It occupies the ridge lying between the valleys of North Platte River and Pumpkinseed Creek, and to the southwest it is exposed in the slopes of the tablelands next south. The formation consists mainly of fine sand containing characteristic layers of hard, fine-grained, dark-gray concretions, often consisting of aggregations of long, irregular, cylindrical masses. These, for convenience, have been called "pipy concretions." They vary in thickness from a few inches to several feet, but from 10 to 15 inches is a fair average. Their trend is east-northeast and west-northwest with surprising regularity. The layers are often many square yards in area. A typical exposure of the concretions is shown in Pl. XVIII, *B*. The sands vary from loose to fairly compact, and some are argillaceous. The colors are uniformly light gray. Owing to the presence of the hard concretions, the formation generally gives rise to ridges of considerable prominence. The steep escarpment of Pine Ridge consists almost entirely of Arikaree cliffs, of which typical views are given in Pls. VIII, XVII, and XXI. The relations of the Arikaree formation to associated deposits are particularly well exposed in the slopes adjoining the Platte and Pumpkinseed valleys. The formation lies on the Gering beds at many points,

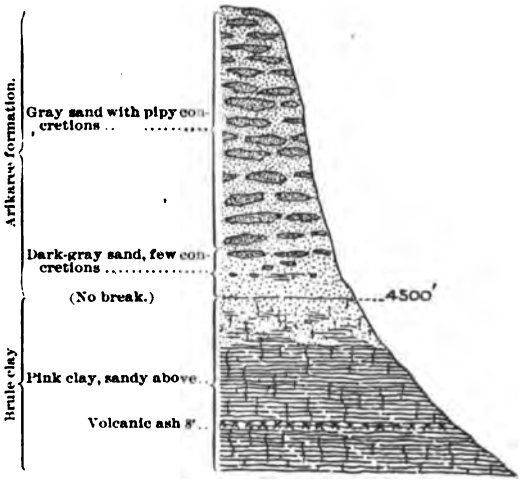


FIG. 2.—Section 6 miles west of Gering, Nebr., showing relations of Arikaree and Brule formations.

but in some areas appears to rest immediately on the surface of the Brule clay. There is often no evidence of unconformity in either case. Usually there is an abrupt change in the character of the materials as the coarse beds of the Gering formation give place to fine massive Arikaree sands containing the pipy concretions. In some cases this concretionary development appears to have extended down into the Gering sediments, especially locally where these sediments are fine sands. This relation is illustrated in fig. 2, and possibly also in fig. 14, on page 35.

There is a possibility that the upper member of the Gering formation is a basal portion of the Arikaree formation, as suggested at some localities, which would often add difficulty to the identification of the Gering formation where it consisted of only one member. Along the north side of the Platte Valley, the south side of the Pumpkinseed Valley, and in portions of the ridge between these two valleys the Arikaree formation appears to lie directly on the Brule clay. In these instances there is often either only a faint suggestion of unconformity between the two formations when the exposures are carefully examined or simply a very rapid change from sandy, pinkish Brule clay, with some small siliceous concretions, to fine gray sands with the typical character and pipy concretions of the Arikaree formation. Fig. 3 shows the usual relations presented in the exposures along the north side of the Platte Valley.

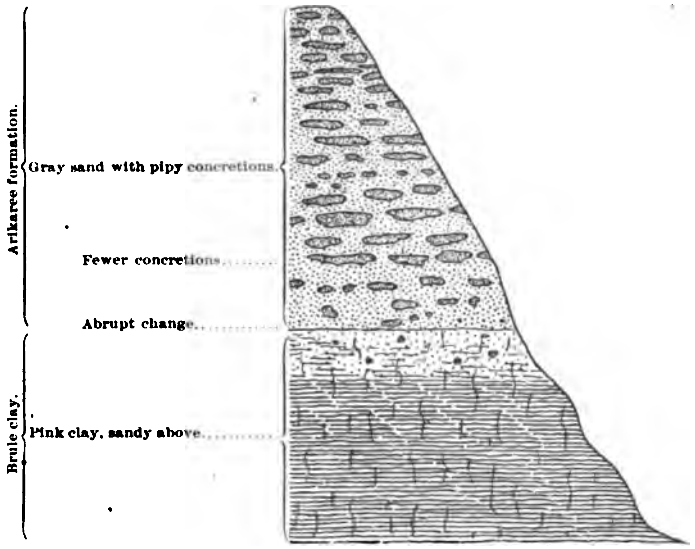
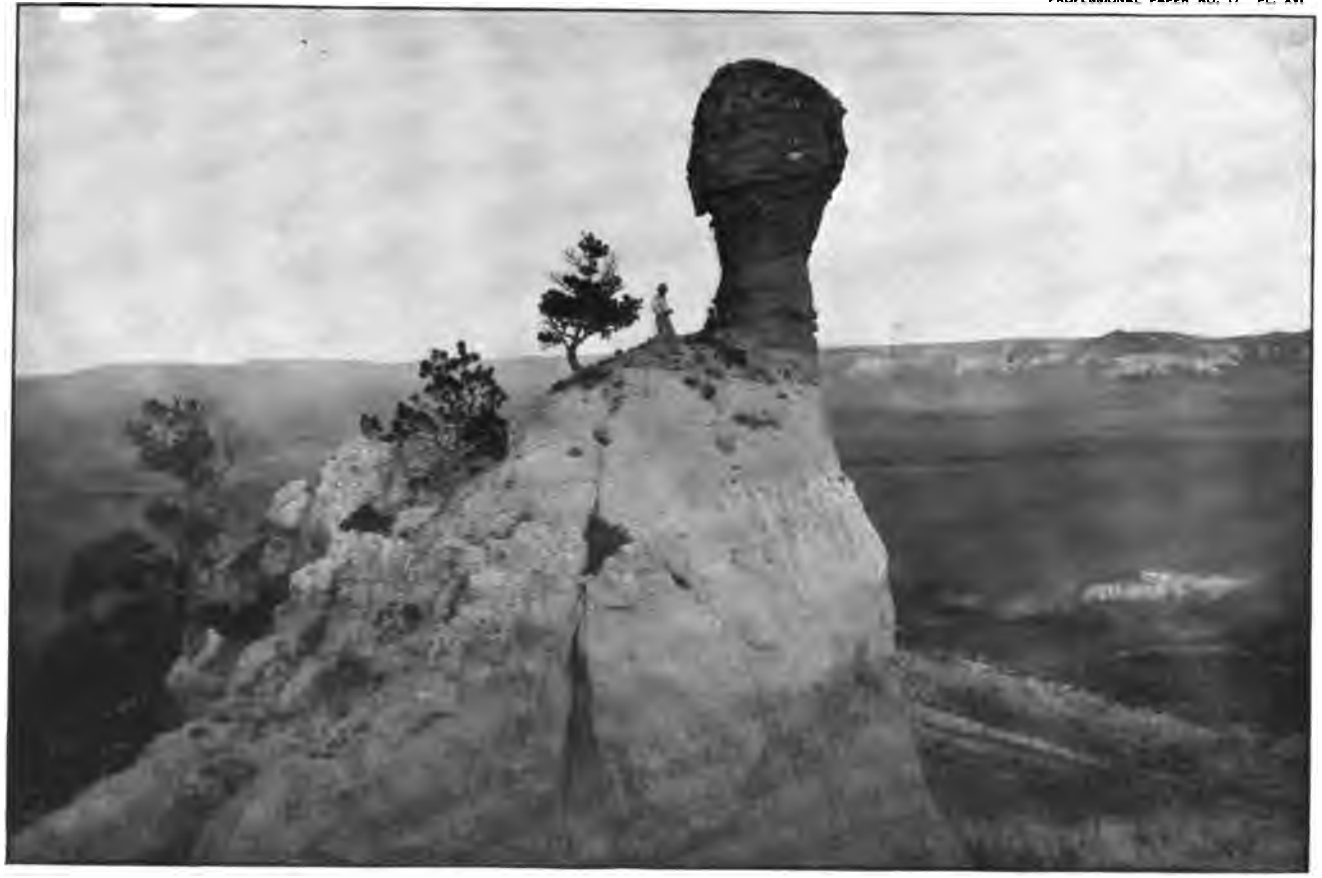


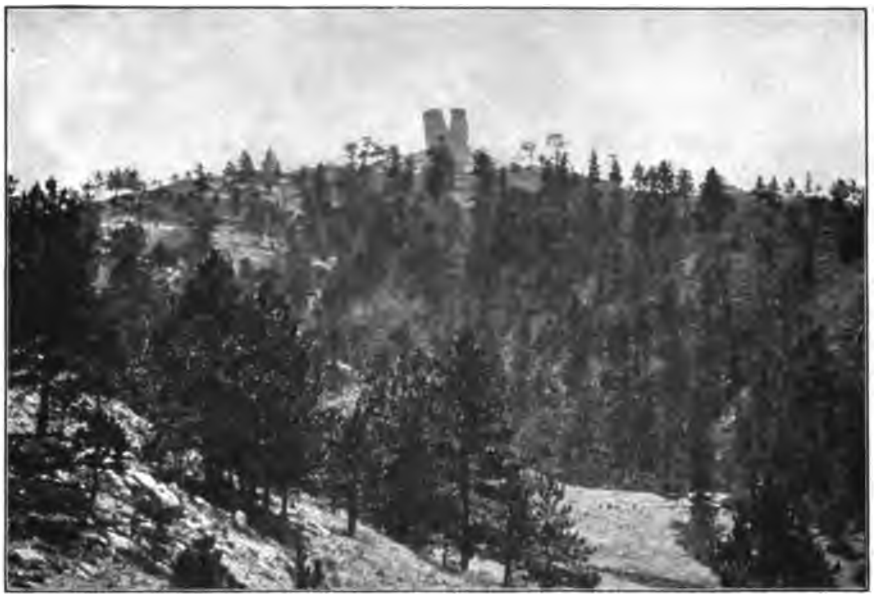
FIG. 3.—Section of Arikaree and Brule formations on the north side of the valley of North Platte River.

In Pl. XVII, *B*, is shown an exposure in which there is marked unconformity between Arikaree and Brule deposits, and other exhibitions of similar relations are shown in sections *A* and *C* of Pl. XV, sections *C* and *D* of Pl. XXVII, and Pls. XXVI and XXVIII. The relations of the Arikaree formation to the Ogalalla formation are described on page 24. The two formations are sharply separated by

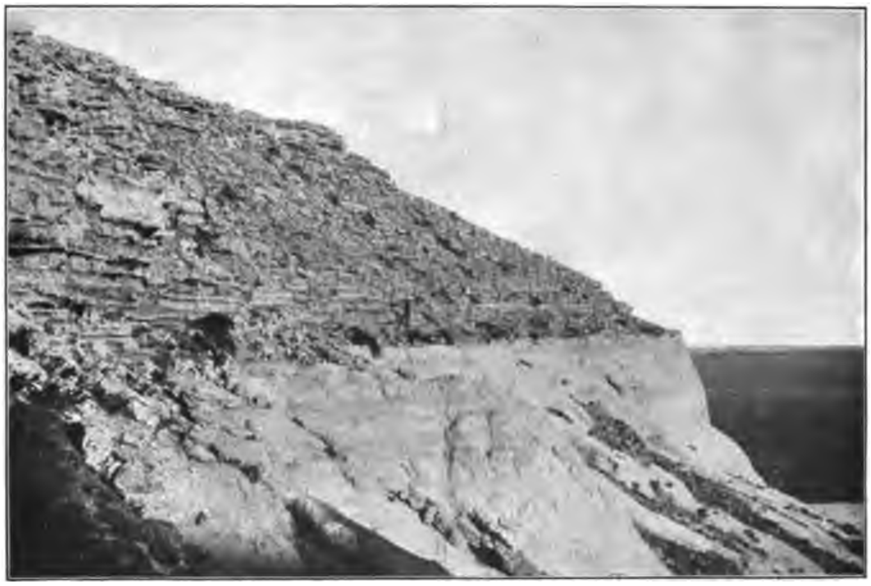


SMOKESTACK ROCK, LOOKING EAST; NEAR VIEW.

Conglomerate in Arikaree formation.



A. BUTTE OF ARIKAREE FORMATION, SOWBELLY CANYON, SIOUX COUNTY, NEBR.



B. ARIKAREE FORMATION ON BRULE CLAY, SOUTHWEST PORTION OF SIOUX COUNTY, NEBR.

an abrupt change in character of materials, and the basal Ogalalla beds are mainly conglomeratic. The thinning out of the Arikaree deposits to the southeast is clearly illustrated in many exposures south of Redington. All along the northern edge of the table-land in Banner County the formation has less thickness than it presents in the ridge north, where, in the vicinity of Wildcat Mountain, it is nearly 500 feet thick. Southwest of Harrisburg the amount is about 150 feet; south of Freeport it is 100 feet, as shown in Pl. XV, *A*; in Hackberry Canyon it is 40 feet; and at Langs Point Arikaree beds are absent, the Ogalalla conglomerate here lying directly on the Brule clay, as shown in section *B* of Pl. XV. Southeast of Langs Point there are a few thin outlying lenses of Arikaree beds, one of which is shown in section *C* of Pl. XV, but thence to the east it thins out and the typical relations presented are those shown in section *D* of Pl. XV. In the upper portion of the valley of Lawrence Fork there is an outlying area of the formation, only a few feet thick, between supposed Gering and Ogalalla formations, as shown in fig. 8 (p. 31).

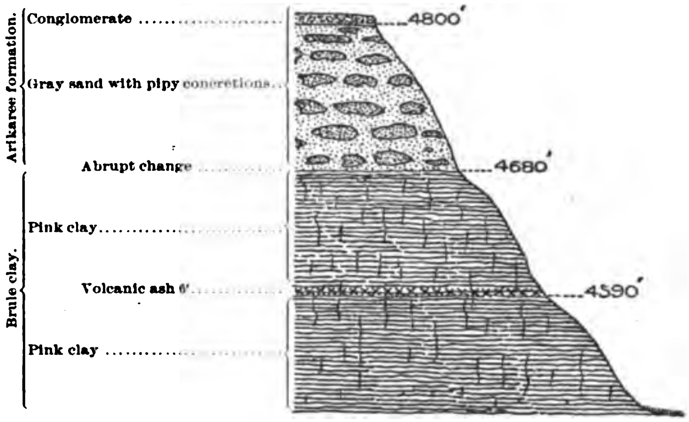


FIG. 1.—Section 3 miles northwest of Dorrington, Nebr., showing the relations of conglomerate in Arikaree formation.

Dæmonelix in various forms occurs extensively in this formation, and in Pine Ridge, in Sioux County, the large forms of the "Devil's corkscrew" are found in very great abundance in the upper beds of the formation. Prof. E. H. Barbour has described these forms in detail and given an account of their mode of occurrence.[a] The larger forms are most abundant in the upper portions of the depressions north of Harrison, but they were observed also as far east as Andrews, for some distance in the valley of Niobrara River above Royville, and as far west as Lusk, in Wyoming. The smaller forms are very generally present throughout the region, and they also occur in the Ogalalla formation. In Pl. XIX is shown an exposure of typical Dæmonelix beds containing the large corkscrew forms. It is believed that no one observing these fossils in the field would have any doubt as to their vegetal nature.

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[a] Bull. Geol. Soc. America, vol. 8, 1897, pp. 305-314.

In a portion of its area the Arikaree formation has been observed to contain a series of old channels filled with coarse conglomerate. The occurrence of this conglomerate is apparently restricted to the ridge lying next south of North Platte River and to the vicinity of Spoon Butte, near the head of Sheep Creek, in Sioux County. The horizon is somewhat above the base of the formation, and the conglomerate is distinct from some local beds of coarse deposits occasionally noticed at or near the base of the formation.

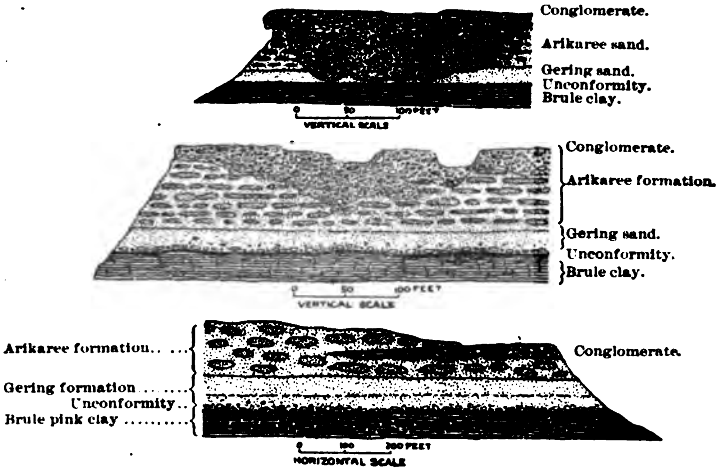


FIG. 5.—Sections 8 miles south-southeast of Gering, Nebr., showing relations of conglomerate in Arikaree formations.

Some of the relations of these conglomerate-filled channels are shown in section *F* of Pl. XXVIII, and in Pls. VI, XIV, and XVI, and fig. 5. Beginning at the east, the first outcrops observed were in Smokestack Rock, in Banner County. They were next seen at intervals westward along the south line of Scotts Bluff County, in buttes and high points, as far west as the meridian of Gering, and detached areas are exposed on the north side of the ridge southwest of Gering. The last outcrop occurs at a point 3 miles north-northwest of Dorrington, near the western end of the ridge, where it has the relations shown in fig. 4.

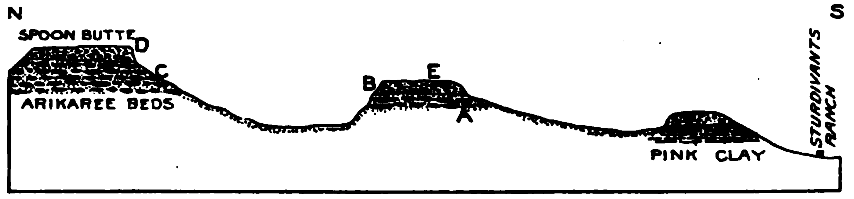
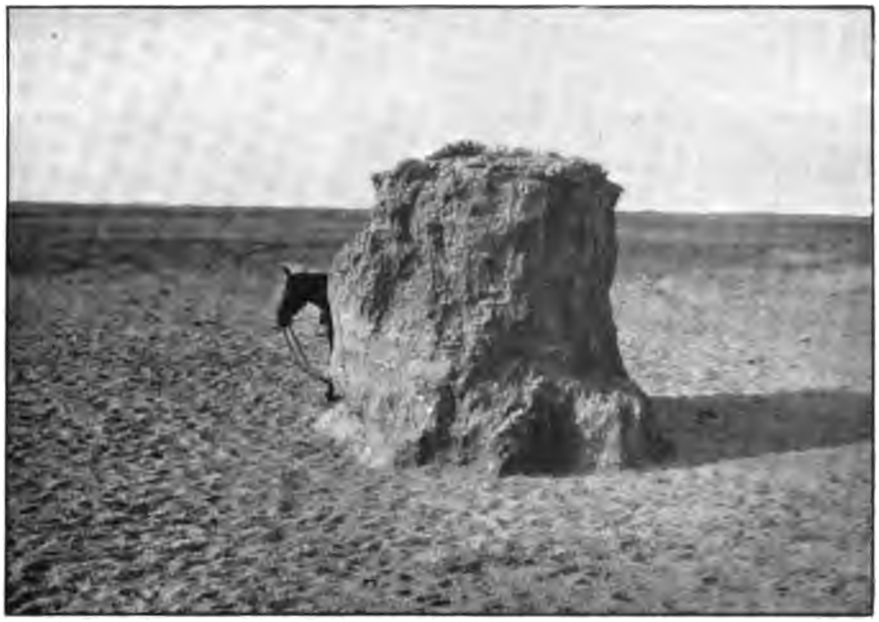
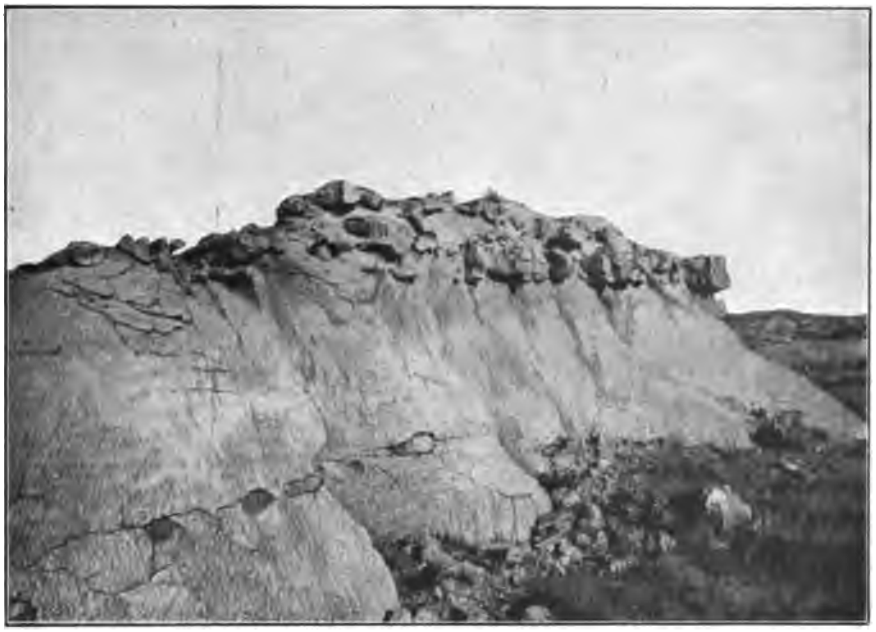


FIG. 6.—Cross section from the eastern end of Spoon Butte southward to Sturdivant ranch, looking east.

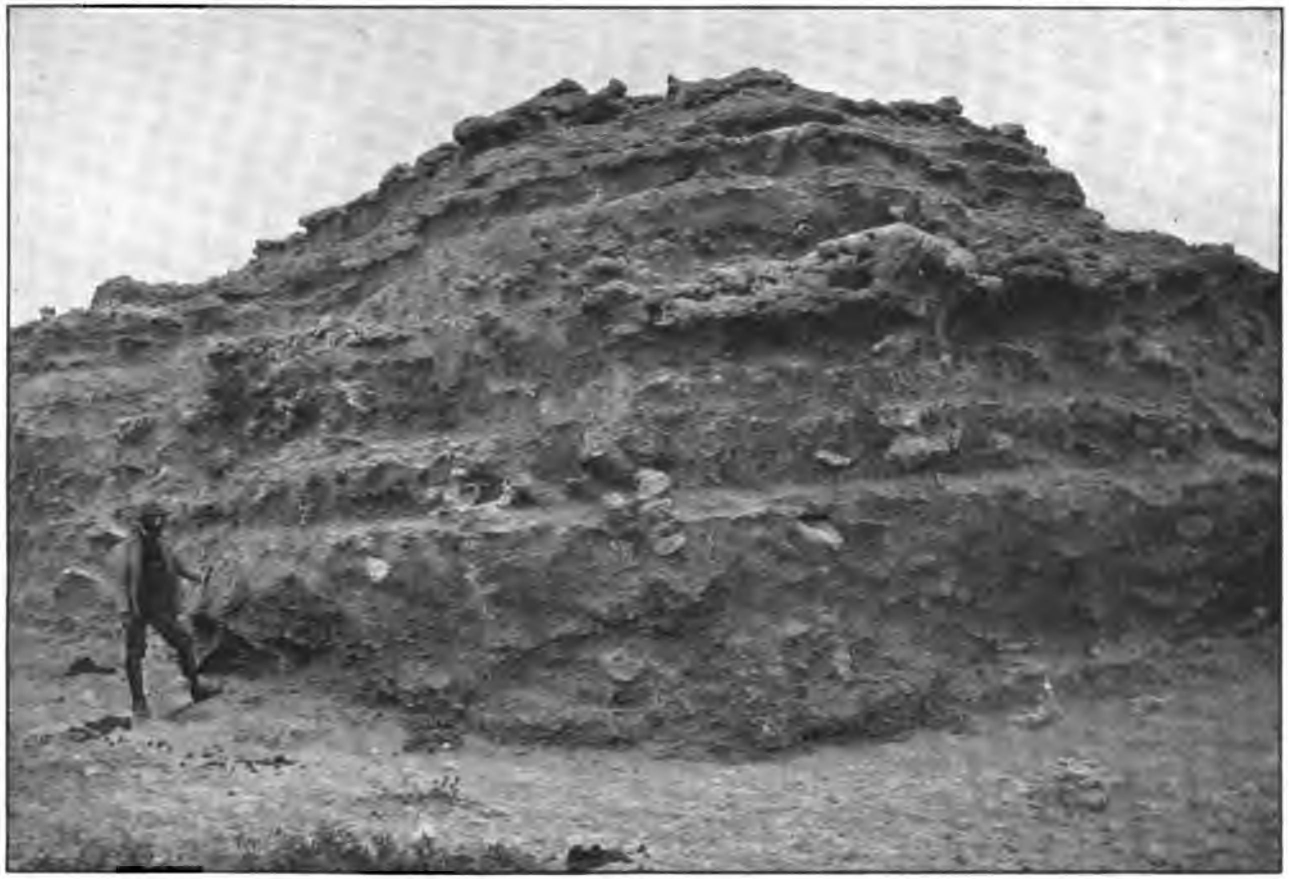
It is probable that the channel is continuous under the ridge between these points. Some features of the more prominent exposures are shown in Pls. XIV and XVI. The material is a conglomerate of pebbles and bowlders of gray sand-



A. BLOWOUT WITH CORE, ARIKAREE FORMATION, SIOUX COUNTY, NEBR.



B. PIPY CONCRETIONS, ARIKAREE FORMATION, SCOTTS BLUFF COUNTY, NEBR.



DÆMONELIX BEDS IN ARIKAREE FORMATION AT HEAD OF LITTLE MONROE CANYON, SIOUX COUNTY, NEBR.

stone, generally firmly cemented by siliceous matrix. The greatest thickness observed was 30 feet, in the high point 3 miles south of Larissa. Smokestack Rock exposes about 25 feet. At many localities it may be seen that the beds lie on typical Arikaree deposits, as shown in Pl. XIV, *B*, and they are overlain by typical beds of the same formation. This relation is shown in fig. 5 (p. 28) and fig. 12 (p. 34).

In the Spoon Butte and adjoining ridges the conglomerates are of somewhat different character, consisting in large part of crystalline rocks and apparently lying on a steeply sloping surface. The relations are shown in fig. 6.

In this vicinity it was not practicable to ascertain the relations to overlying beds.

The Arikaree deposits contain a large amount of volcanic ash, mainly as a constituent intermixed with the sand, but there are also several distinct beds of ash at one or two horizons, though only of local occurrence. The relations of these beds are indicated in section *A* of Pl. XXVIII and figs. 1, 7, 10, 12, and 18, and some further information regarding them will be found on page 42.

Molluscan fresh-water fossils of several species have been found in this formation, but they are not sufficiently distinctive to indicate its age precisely. One abundantly fossiliferous locality was discovered south of Gering, where the matrix was a thin bed of diatomaceous earth. Vertebrate remains were collected in small numbers.

GERING FORMATION.

Underlying the Arikaree formation, in a portion of the area, there is a series of coarse sands, often containing pebbles, which appears to be an entirely distinct formation. It is not separated by unconformity, but it has distinctive characters over an area of considerable extent. In its typical exposures it is separated from the Brule clays by a clearly marked unconformity, some of the features of which are shown in Pl. XXV. Its thickness varies from a thin wedge to over 200 feet. Its relations are extensively exhibited in the ridge lying next south of North Platte River, and it is thick and apparently continuous along the northern face of Pine Ridge. The southernmost exposures are some doubtful ones on Lawrence Fork, near its head. In Pls. XXVI, XXVII, and XXVIII, and figs. 7 to 17, the stratigraphic relations of this formation are illustrated. Its greatest development in the Platte Valley is south-southwest of Gering, where 200 feet are exposed, and about Chimney Rock, where a thickness of about 145 feet is attained. It is over 100 feet thick in Courthouse Rock and in the vicinity of Birdcage Gap and Redington Gap. To the west and south it thins out, and at some points along both sides of the ridge it is apparently absent, or possibly where it appears to be absent it is represented either by clayey members which are not distinguishable from the Brule clay or by fine sand with concretions resembling Ogalalla beds. Its absence is almost certain in the ridge about Wildcat Mountain. In Scotts Bluff the relations of the formation are very distinct and 60 feet are exposed. On the slopes north of Platte River the formation appears to be absent except in a small area near the southwest corner of Sioux County, where the features shown in fig. 7 indicate that the formation is probably present locally.

Along the north face of Pine Ridge the formation presents the features shown in figs. 19 and 20 (pp. 39 and 40) and Pl. XX.

Some further facts and inferences as to its relations are shown in cross sections in Pl. XII. No definite evidence of the continuance of the formation could be found in the slopes south of Pumpkinseed Creek except in the valley of Lawrence Fork, in sec. 4, T. 16, R. 54, where there is an exhibition of the features shown in fig. 8.

In the Lodgepole Valley the Arikaree formation appears to lie directly on the Brule clay, both the Gering and Ogalalla formations being absent.

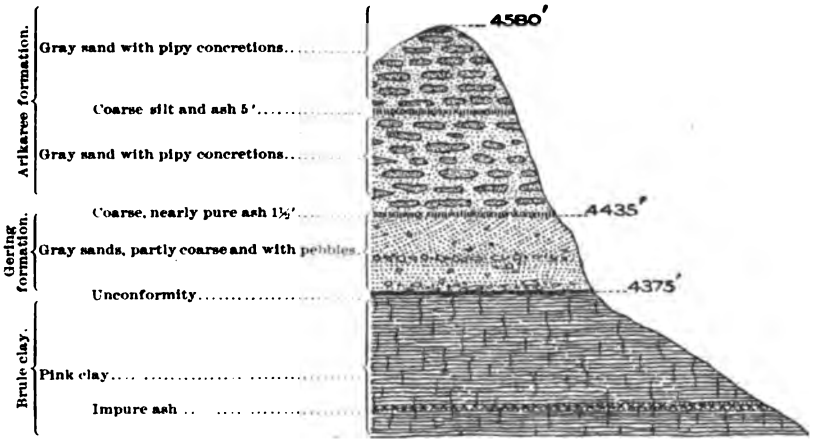
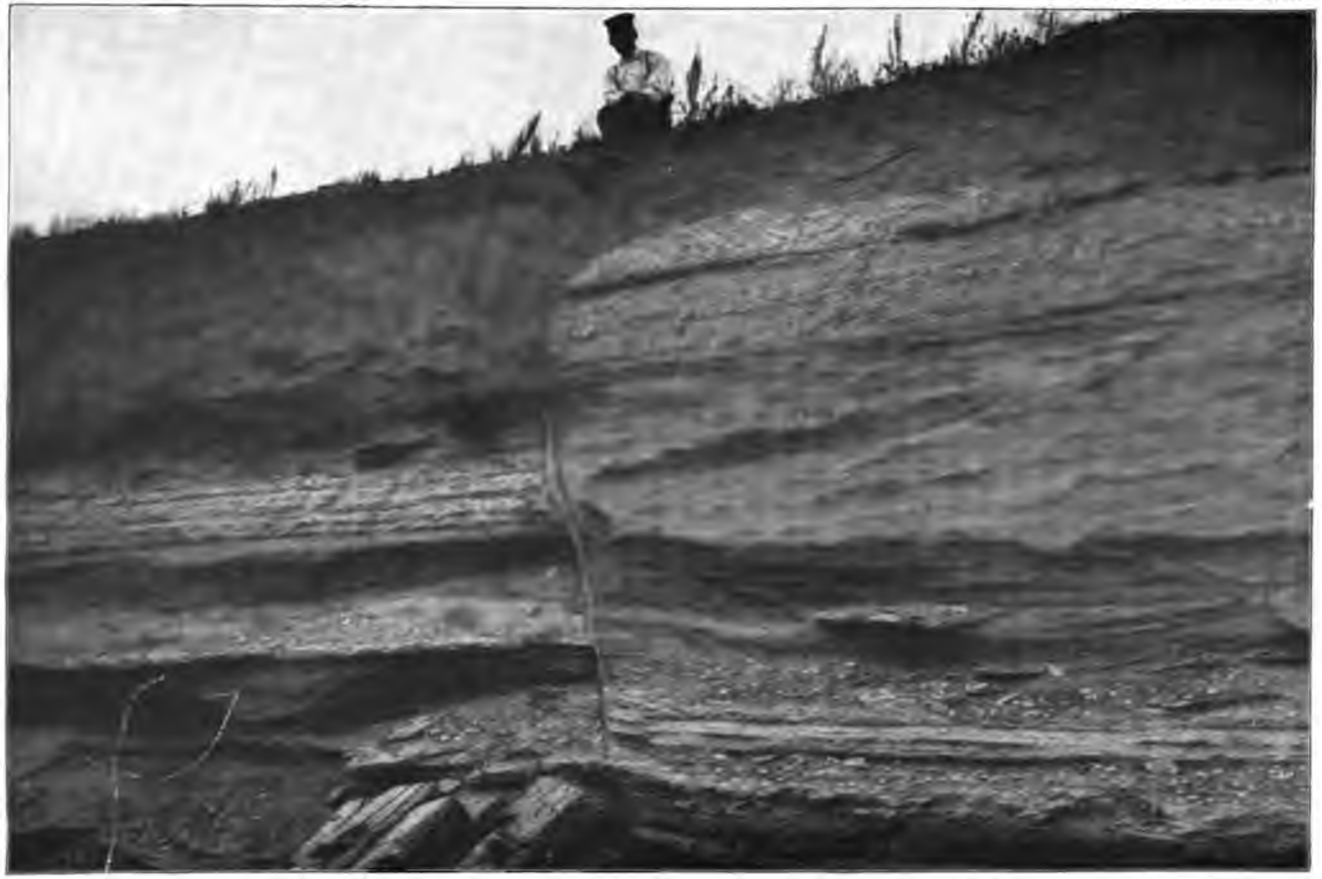
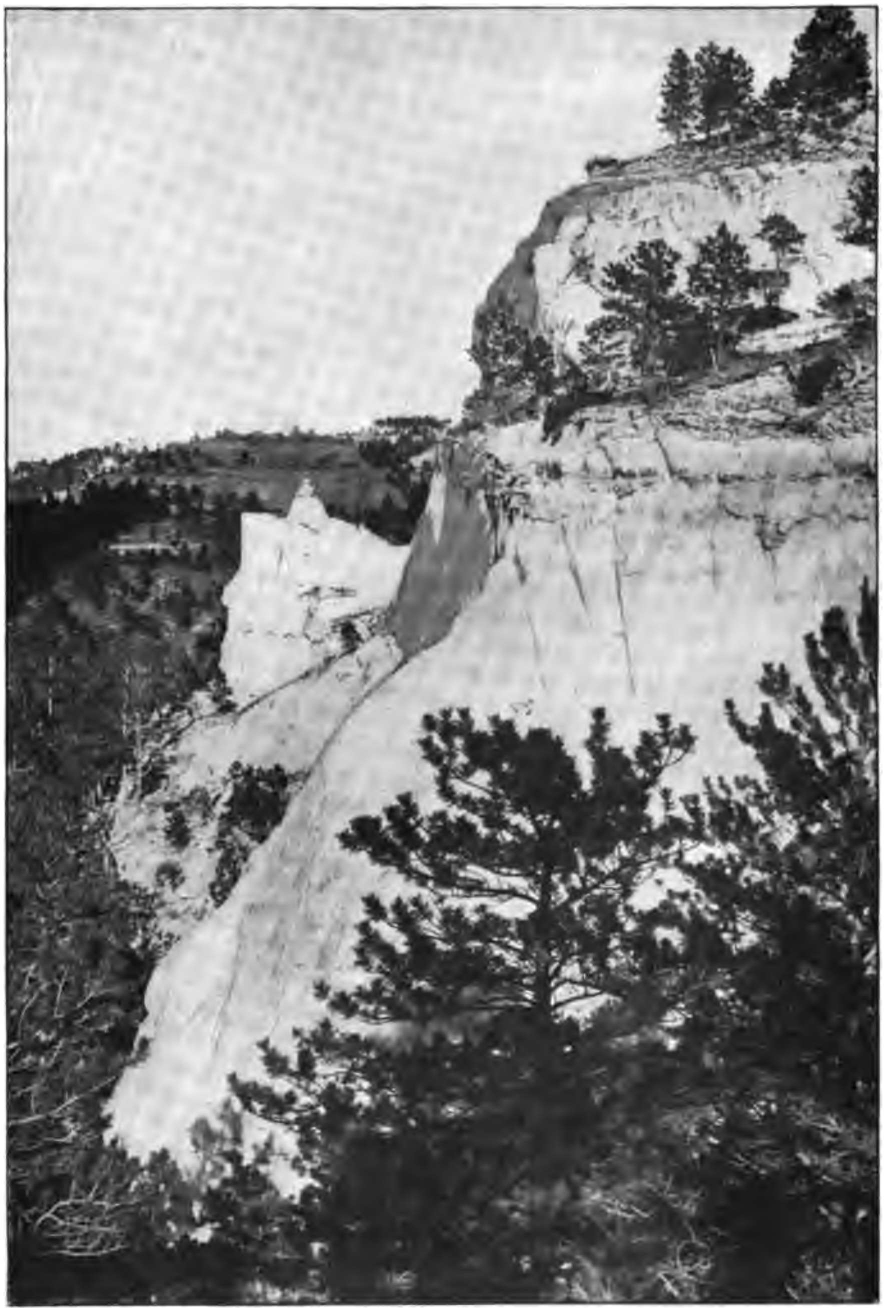

Arikaree formation.
Gray sand with pipy concretions
Coarse silt and ash 5'
Gray sand with pipy concretions
Coarse, nearly pure ash 1½'
Gering formation.
Gray sands, partly coarse and with pebbles
Unconformity
Brule clay.
Pink clay
Impure ash
4580'
4435'
4375'

FIG. 7.—Section of bluff in southwest corner of Sioux County, showing relations of supposed Gering formation.

The Gering formation presents many local features of stratigraphy, particularly in the ridge between the valleys of Platte River and Pumpkinseed Creek. Beginning at Jail Rock, there are instructive exposures at frequent intervals to the western end of the ridge. At Courthouse Rock there are presented the relations shown in section *A* of Pl. XXVI. At an altitude of 3,940 feet the distinctive Brule clay is unconformably overlain by the Gering formation, apparently comprising two members, separated by marked unconformity by erosion. In both members there are coarse beds below containing local conglomerate, merging upward into sand, and finally into sandy clay. The total thickness is 110 feet. The characteristic Arikaree formation capping Courthouse Rock begins abruptly, but with no sign of unconformity. Jail Rock, as shown in Pl. V, is capped by the Gering formation. The two members of this formation present about the same relations at Birdcage Gap as shown in section *B* of Pl. XXVI, but they have somewhat greater thickness. In the pinkish sandy clay, at an altitude of 4,080 feet, there was found a portion of the



GERING FORMATION WITH FAULT, NEAR RUTLAND, DAWES COUNTY, NEBR.



CLIFFS OF ARIKAREE FORMATION, NORTH FACE OF PINE RIDGE, NEAR MONROE CANYON, SIOUX COUNTY, NEBR.

(From photograph by E. H. Barbour, University of Nebraska.)

skeleton of a new species of *Dinictis*.[a] A view of the relations in Birdcage Gap is given in Pl. XXII.

At Redington Gap the upper member of the Gering formation is not distinguishable, and the total thickness is less. A local bed of volcanic ash 5 feet thick appears to mark the top of the formation. The principal features are shown in section *C* of Pl. XXVI. Three miles northwest of Redington Gap there was found the section shown in Pl. XXVI, *D*. The Gering formation here presents the usual basal beds of coarse material lying unconformably on the Brule clay. The change to the Arikaree formation above is abrupt, but not marked by unconformity.

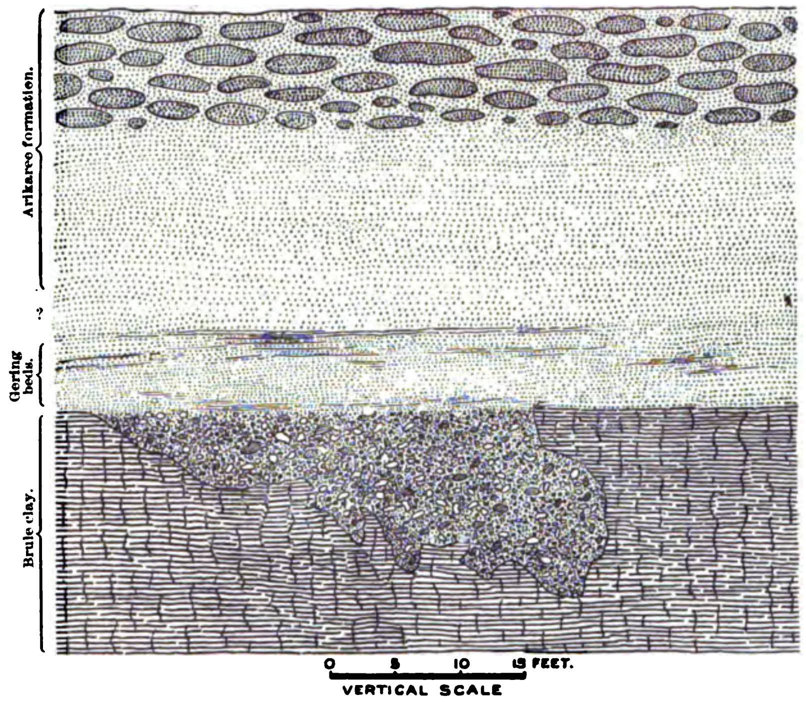


FIG. 8.—Details of unconformity between Brule clay and supposed Gering deposits in valley of Lawrence Fork, sec. 4, T. 16, R. 54.

Approaching Chimney Rock there are presented the features shown in sections *E* and *F* of Pl. XXVI. The thickness of the Gering formation here averages about 125 feet, and there is much local variation in the stratigraphy. Coarse basal beds are often exposed lying unconformably on the Brule clay. A thin local bed of volcanic ash is conspicuous in some exposures. Chimney Rock consists of a spire of Gering formation rising from a conical hill of Brule clay. The material is a gray, thin-bedded, soft sandstone with slightly coarser materials at its base. The unconformable contact with the Brule clay is at an altitude of 4,100 feet, and there is here considerable carbonaceous material, strongly suggestive of an old soil. At an altitude of 4,135 feet there is a faint unconformity, just above which there are two thin beds containing volcanic ash. Two views of Chimney Rock are given in Pl. XXIV, and the relations of the formations are shown in section *A* of Pl. XXVII.

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[a] Recently described by F. A. Lucas as *Dinictis major:* Am. Jour. Sci., 4th series, vol. 6, 1898, pp. 399-400.

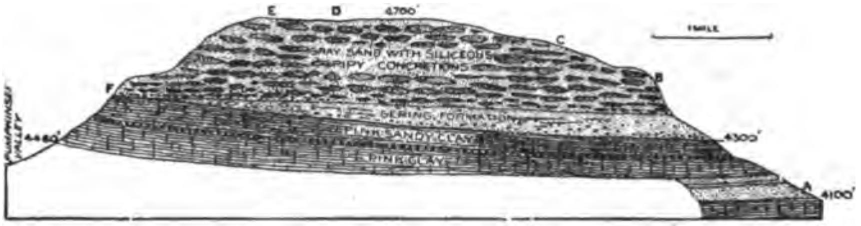


FIG. 9.—Cross section of ridge 10 miles south of Gering, Nebr., looking west.

Southwest of Chimney Rock the Gering formation greatly decreases in thickness, but it continues to present its characteristic features, as shown in sections *B* and *C* of Pl. XXVII. The two members are well characterized as far as the east side of Sheep Mountain. Along the south side of this butte the basal member of the Gering formation is, in places, not clearly separable.

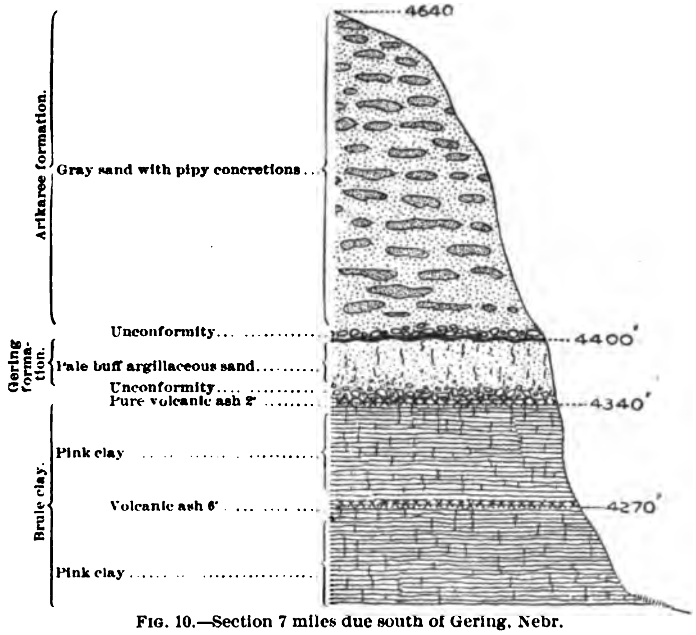
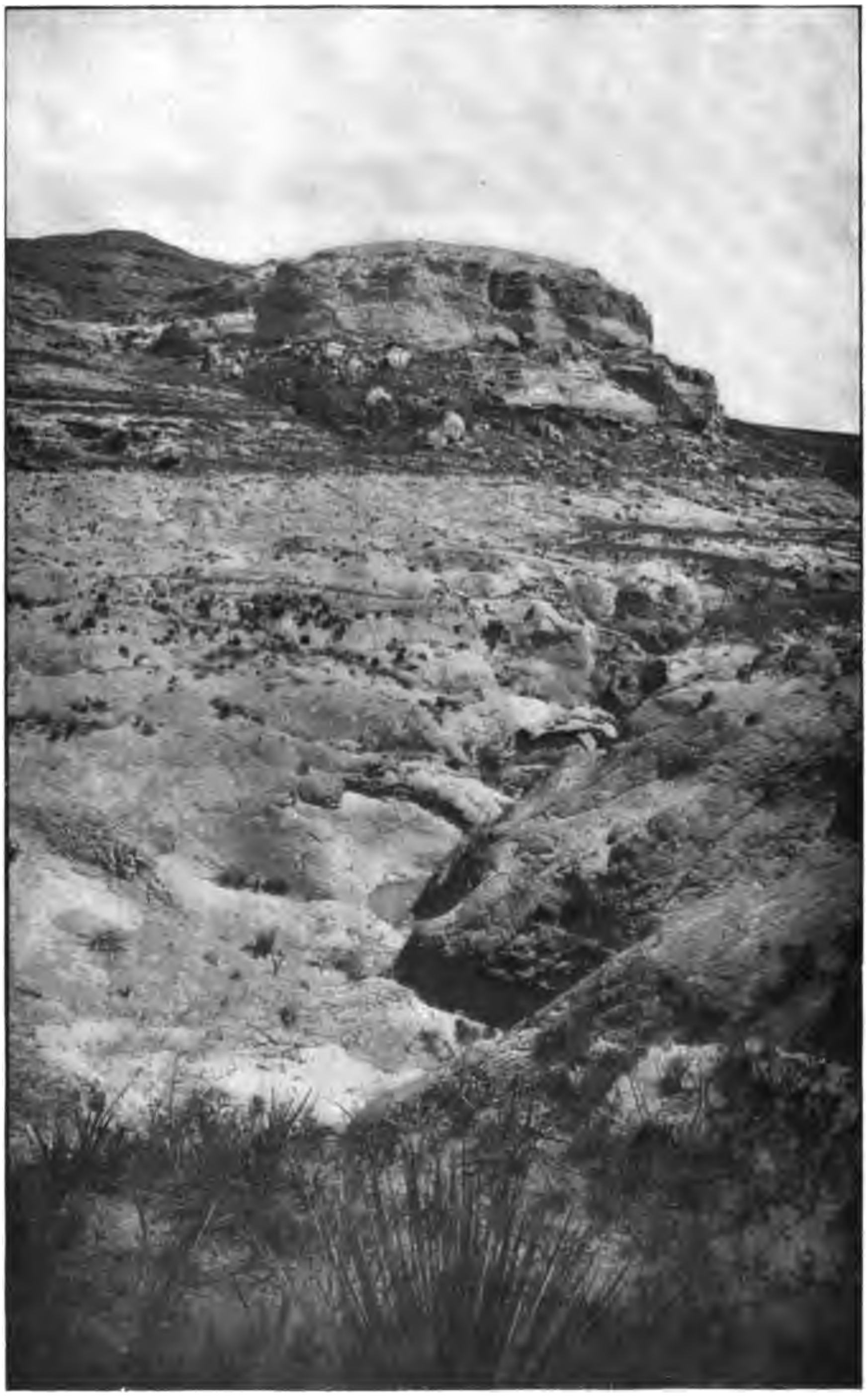


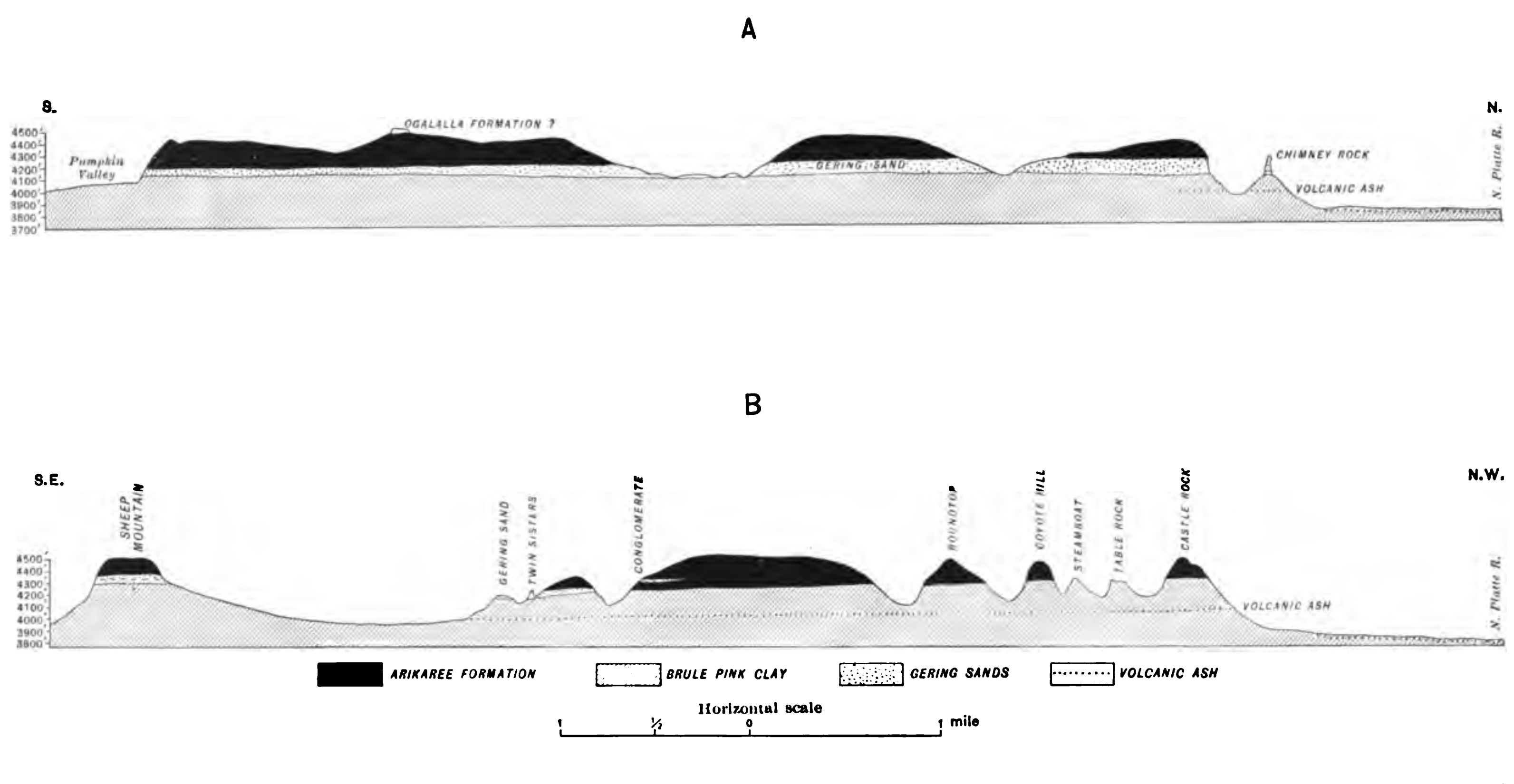
FIG. 10.—Section 7 miles due south of Gering, Nebr.

At the curiously sculptured Twin Sisters, which are of Gering formation, the unconformity is finely exhibited, as shown in Pl. VII, *A*. The materials consist of coarse sands and soft sandstone, merging upward into a 6-foot bed of pinkish sandy



ARIKAREE FORMATION, GERING FORMATION, AND BRULE CLAY, IN BIRDCAGE GAP, CHEYENNE COUNTY, NEBR.

Looking northeast through the gap.



CROSS SECTIONS, SHOWING RELATIONS OF FORMATIONS NEAR CHIMNEY ROCK AND HORSESHOE FLAT, NEBR.

A, Near Chimney Rock; *B*, near Horseshoe Flat.

clay, above which there is a moderately sharp break, followed by an upper member of gray sand which constitutes the heads and shoulders of the "Sisters." Some of the relations in this vicinity are shown in section *B* of Pl. XXIII, which also shows the apparent thinning out of the formation a short distance northward.

The Gering formation appears to be absent at the Smokestack and in Round Top, Coyote Hill, and Castle Rock. In Castle Rock, as shown in section *D* of Pl. XXVII, the Brule clays become sandy in their upper portion, but present no suggestion of stratigraphic break until the base of the well-characterized Arikaree deposits is reached, at an altitude of 4,340 feet, where there is an unconformity marked by a bed of white clay a foot thick on a carbonaceous surface strongly suggestive of old soil. This soil and the relations of the formation indicate that there was here a land surface while the Gering formation was being deposited to the south.

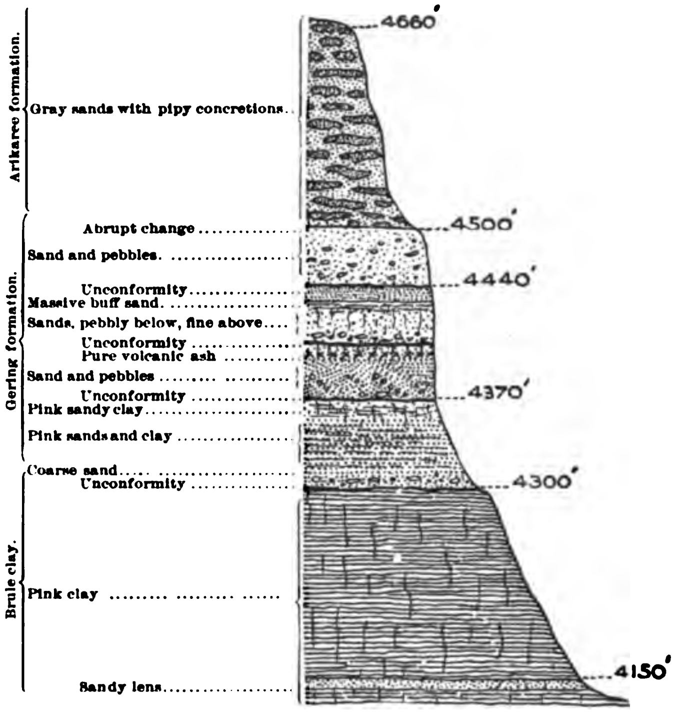


FIG. 11.—Section of Gering and associated formations 6 miles south-southwest of Gering, Nebr.

The Gering formation extends continuously for several miles west from the Twin Sisters. At a point 4 miles west-northwest it has the relations shown in section *F* of Pl. XXVIII, consisting of two members with an aggregate thickness of 120 feet. It contains the usual coarse beds at the base of each member, and in the base of the lower member there is a 2½-foot bed of pure volcanic ash. In the next bluff, 1½ miles northwest, there are exposed the features shown in section *C* of Pl. XXVIII.

In the next 1½ miles the formation thins rapidly, as shown in section *B* of Pl. XXVIII, and it appears to thin out locally to the south and at intervals to the west.

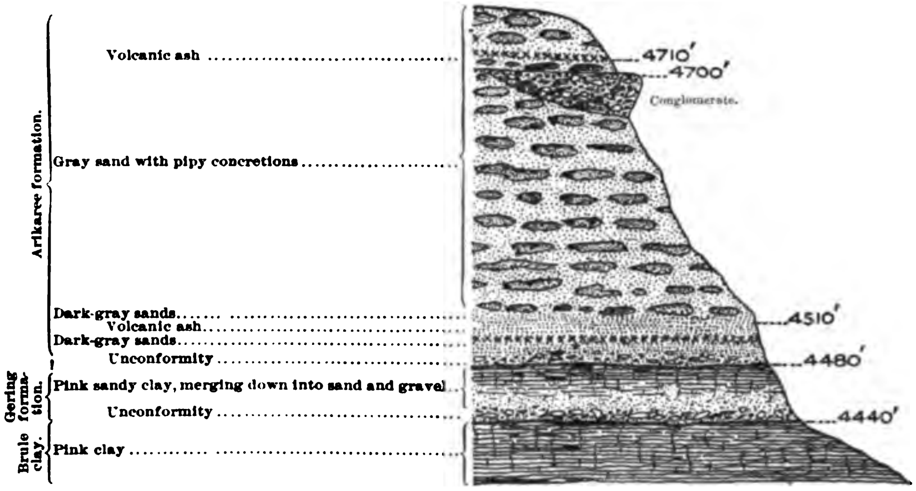


FIG. 12.—Section of Gering and associated formations 7 miles south-southwest of Gering, Nebr.

In the high butte 2½ miles west-southwest of Larissa, as shown in section *A* of Pl. XXVIII, the Gering formation is probably represented by a thin wedge of laminated sandstone, which is exposed on the south slope, but is absent to the north. In the buttes south of Gering the formation occurs in irregular masses, and for some

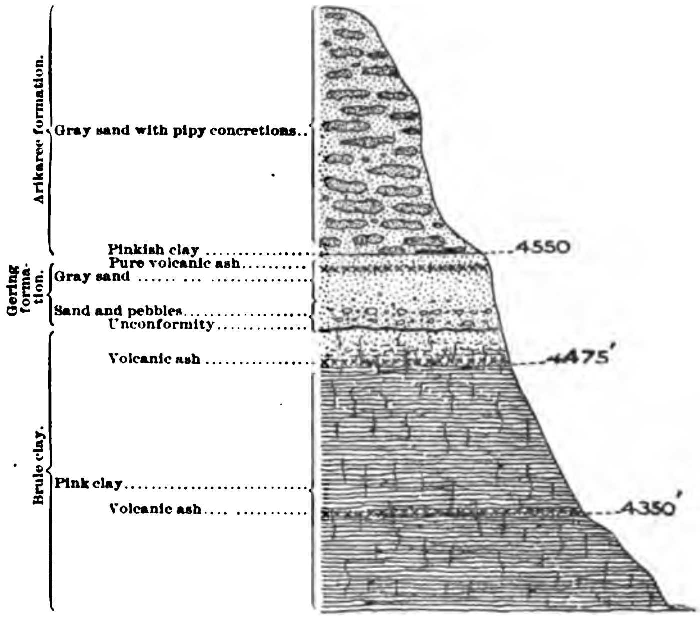
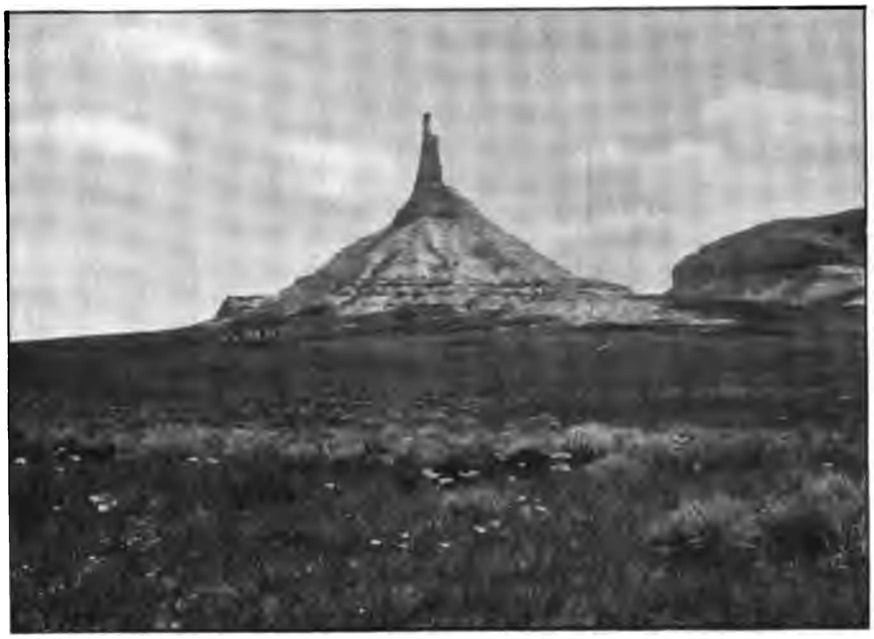
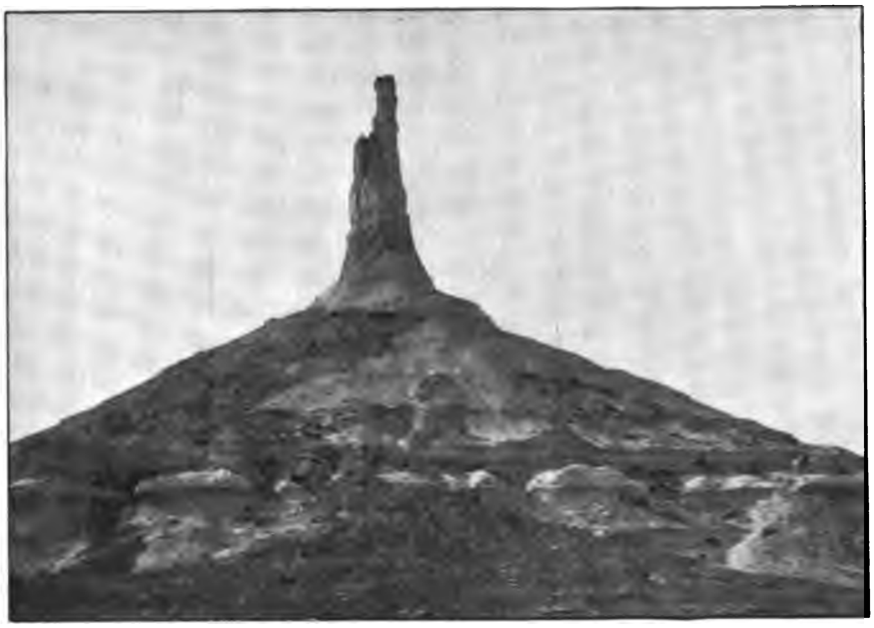


FIG. 13.—Section of Gering and associated formations in Cedar Canyon, 8 miles southwest of Gering, Nebr.



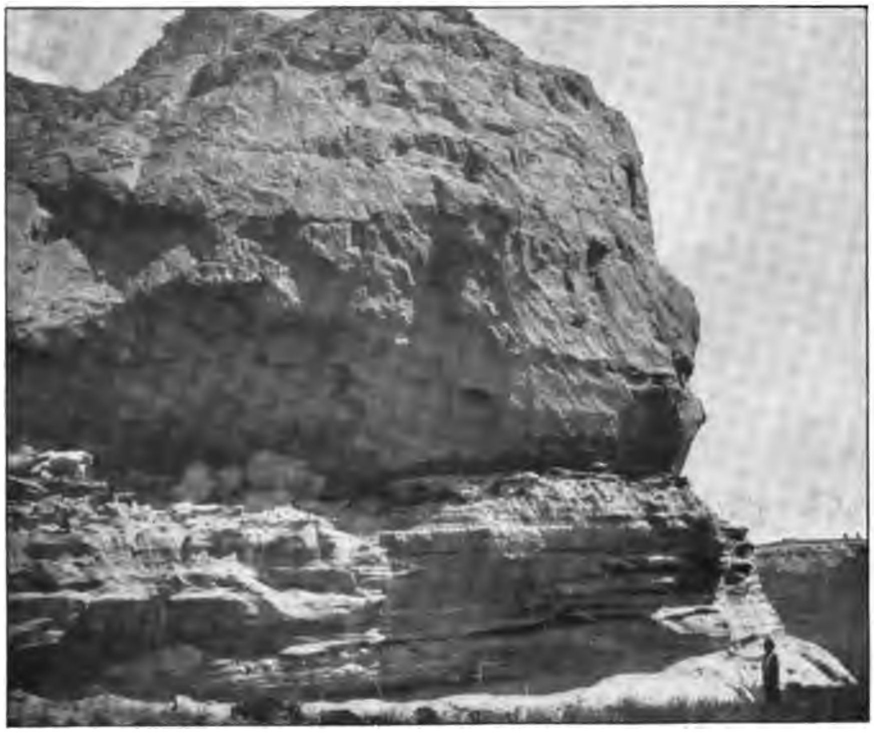
A.



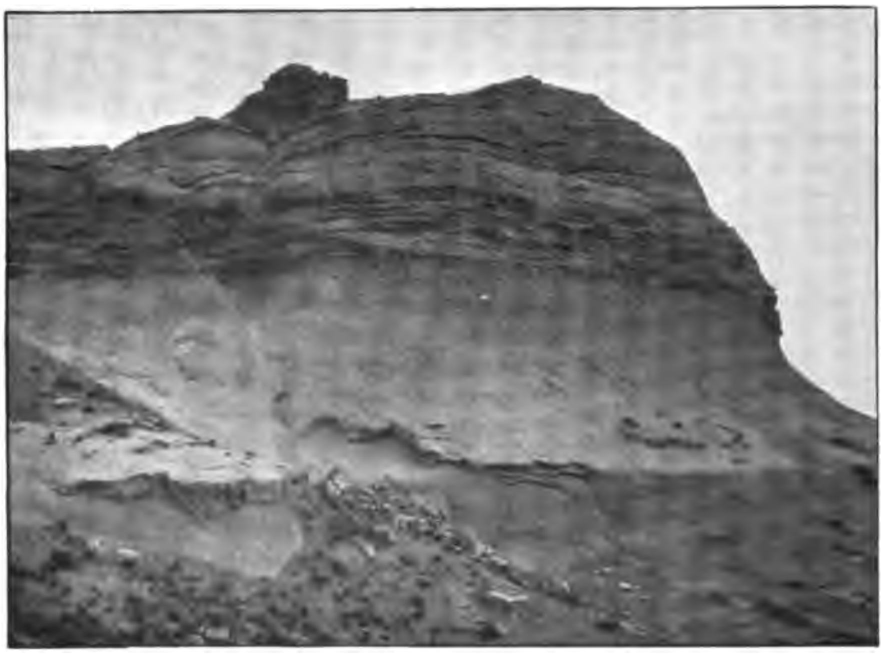
B.

CHIMNEY ROCK, CHEYENNE COUNTY, NEBR.

A From the west, showing volcanic-ash bed; *B*, from the east, Gering sandstone on Brule clay (the horse is on a bed of volcanic ash).



A.



B.

GERING FORMATION, LYING UNCONFORMABLY ON BRULE CLAY, CHEYENNE COUNTY, NEBR.

A, With conglomeratic beds, 4 miles northwest of Redington (the man's hand is at the contact); *B*, 2 miles southwest of Chimney Rock.

distance is not over 50 feet in thickness. Its relations in this vicinity are shown in fig. 9, at B and C. At *B* in this section the Gering beds consist of sand and sandy clay, with streaks of conglomerate at their base. There is a very abrupt change to Arikaree beds at their summit. The details of stratigraphy at *B* are shown in fig. 10.

At this exposure there is a bed of volcanic ash in the base of the Gering formation, with alternations of sands and sandy clays above to a sharp unconformity at 4,390 feet. Above this unconformity are sands, pebbly at base, which appear to merge up into the Arikaree beds. They may, however, constitute the upper member of the Gering formation.

In the very prominent point in the northwest corner of T. 20, R. 55, 6 miles south-southwest of Gering, the formation attains its maximum development for this district, having a thickness of 200 feet and the composition shown in fig. 11.

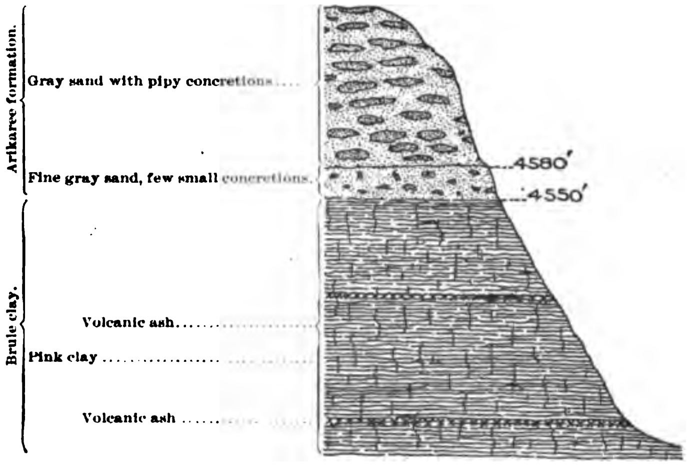


FIG. 14.—Section of Gering and associated formations at the mouth of Cedar Canyon, 7 miles southwest of Gering, Nebr.

A mile south of this exposure the Gering beds have the character and relations shown in fig. 12, which illustrates the thinning to the south.

The unconformity at 4,480 feet may be either in the Gering formation, separating it into two members, or at the base of the Arikaree formation, here including coarse beds and a thin layer of nearly pure volcanic ash. West of this vicinity the formation again thins rapidly, and on the north side of the upper part of Cedar Canyon it has the relations shown in fig. 13.

One mile northeast of this exposure, in the high point at the mouth of Cedar Canyon, the formation is only doubtfully recognized, with the relations shown in fig. 14. In other places to the west and north for some distance the formation is either absent or very thin and not well characterized.

In the Scotts Bluff ridge west of Gering the Gering formation has a thickness of 60 feet. It is finely exposed in the butte of which Scotts Bluff is the north face, where its relations are as shown in fig. 18. Some of its features may also be seen in Pl. XXIX. Dome Rock exhibits 50 feet of the Gering formation, capped by a small mass of Arikaree formation. In the vicinity of Signal Butte the Gering formation appears to be represented by 60 feet of laminated dark-gray sands or soft sandstone lying unconformably on the Brule clay, the unconformity being strongly marked. At the top of the butte there is a cap of thin, hard, white calcareous deposit, which extends widely in the vicinity. The relations are shown in fig. 15.

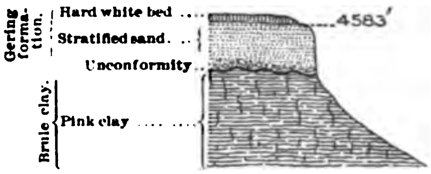


FIG. 15 —Section at Signal Butte, Scotts Bluff County, Nebr.

The Gering formation is developed in places north of Dorrington with the relations shown in fig. 16. The thickness is 50 feet, and the coarse basal beds lying uncomformably on the Brule clay are finely exposed at several points. The formation also here contains a thin bed of volcanic ash near the top.

Along the south side of the ridge from Dorrington to Ashford the formation is either absent or not characteristic. Near Funnel Rock the Arikaree beds lie unconformably on the Brule clay, as shown in fig. 17. In the region north-northeast of Ashford the Gering formation is very distinct again for a few miles, especially high up in the canyons which are cut into the ridge. In two of these canyons the outcrop is marked by large springs. The relations in this vicinity are represented at D, E, and F in fig. 9 (p. 32). At D, high up a canyon, there is a fine exposure of 50 feet of coarse Gering beds lying unconformably on Brule clay and fairly sharply separated from Arikaree beds. At E, farther down the canyon, similar relations are exhibited. At F, on the point at the mouth of the canyon, there is no trace of the coarse beds; the fine sand, similar to that of the Arikaree deposits, but with smaller and more widely scattered concretions, lying directly on the Brule

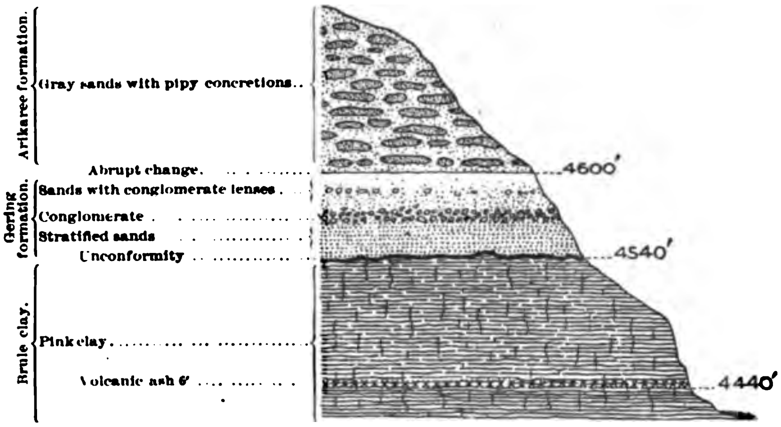
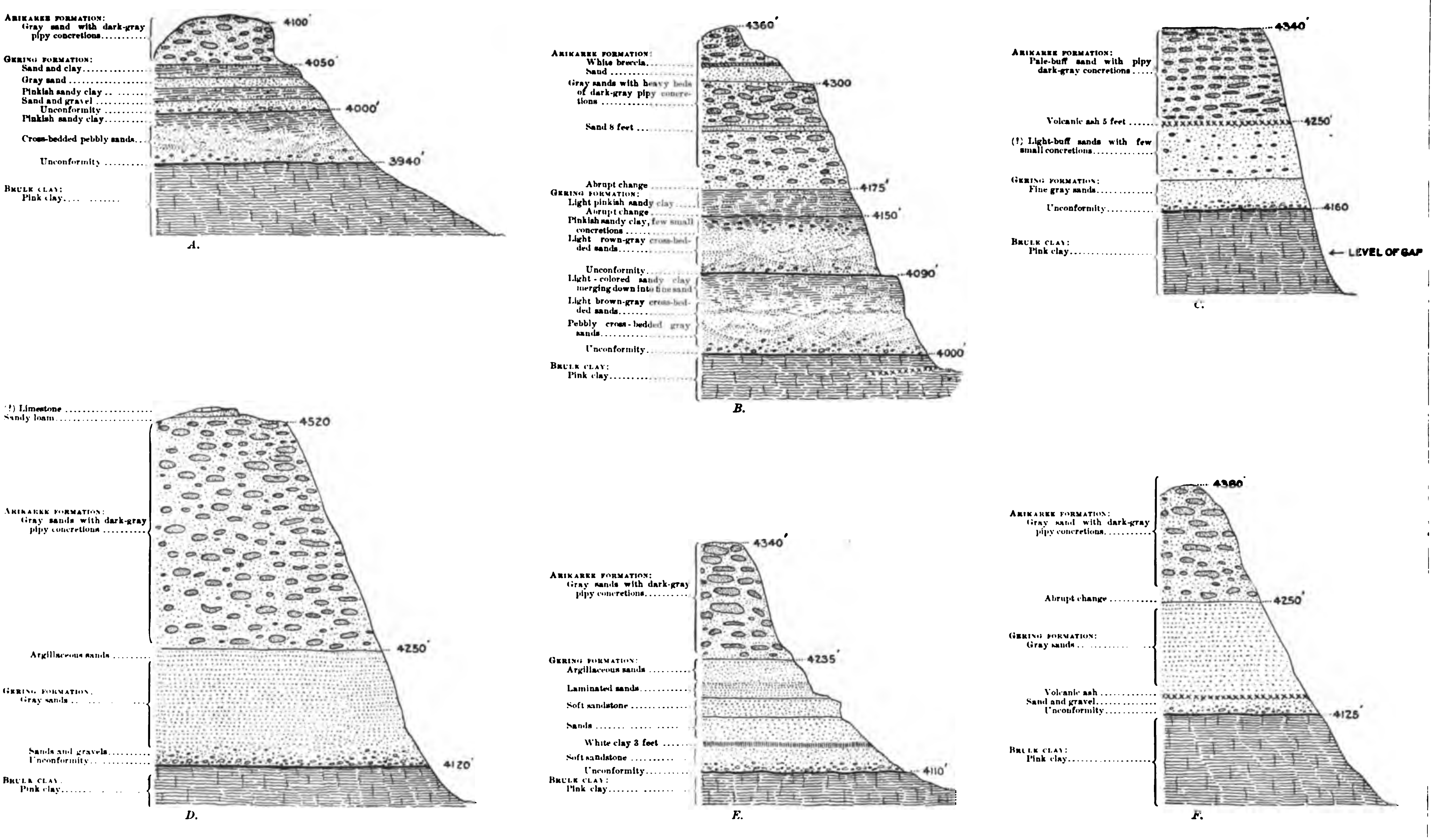
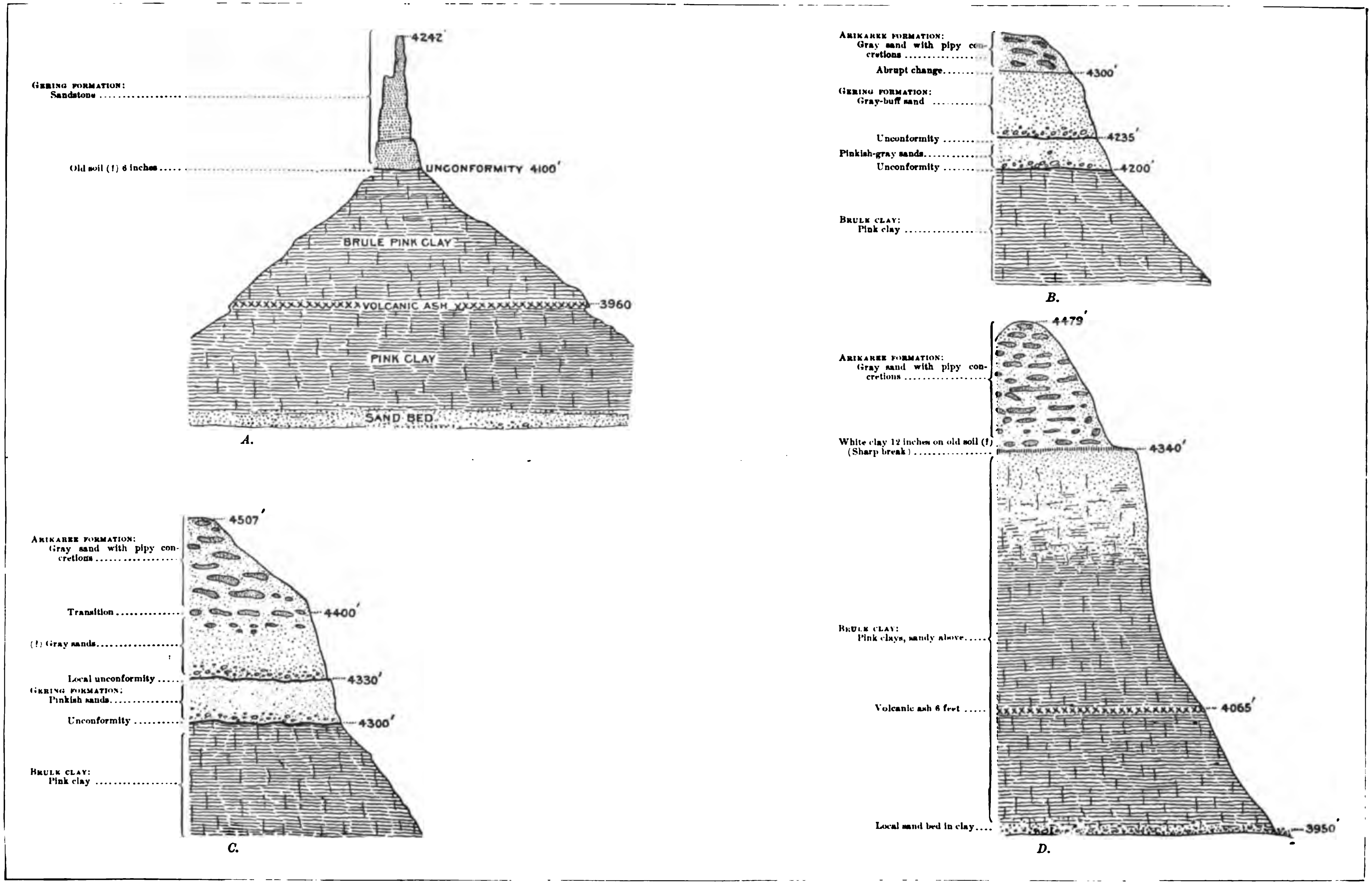


FIG 16.—Section of Gering and associated formations 2 miles northeast of Dorrington, Nebr.



SECTIONS OF EXPOSURES SHOWING THE RELATIONS OF GERING AND ASSOCIATED FORMATIONS, CHEYENNE COUNTY, NEBR

A. At Courthouse Rock; *B*. at Birdcage Gap; *C*. at Redington Gap; *D*. 4 miles south-southeast of Chimney Rock; *E*. 3 miles south-southeast of Chimney Rock; *F*. 1 mile south of Chimney Rock.



SECTIONS OF EXPOSURES SHOWING THE RELATIONS OF GERING AND ASSOCIATED FORMATIONS FROM CHIMNEY ROCK TO CASTLE ROCK.

A, At Chimney Rock; *B*, 3½ miles southwest of Chimney Rock; *C*, at Sheep Mountain; *D*, at Castle Rock.

clay, with faint unconformity apparent. Farther east, at Castle Rock, in Banner County, and in the prominent point 1½ miles west of this rock, the identity of the formation is not satisfactorily established. The relations at these localities are shown in sections *D* and *E* of Pl. XXVIII. In the bluffs on the south side of the ridge, northeast of Redington, the Gering formation is again recognized. Its unconformity to the Brule clay is often finely exposed in this vicinity, as shown in Pl. XXV, *B*.

BRULE CLAY.

This thick mass of sediment which underlies the greater part of the region consists mainly of massive clay or a mixture of fine sand and clay, of pale flesh color, containing numerous fossil beds characteristic of the Oreodon series of the White River group. It is widely exposed in the valleys of North Platte River and Pumpkinseed Creek, extends along the lower portion of the northern slope of Pine Ridge, and is bared in the narrow depression of Lodgepole Creek and Sidney Draw. In the valley of the North Platte it is often widely overlain by alluvial deposits, and this also is the case to a less degree in the smaller valleys. Along the foot of Pine Ridge the formation is largely covered by wash and talus, and by a small amount of alluvium along White River and its tributaries. The formation underlies all the high table-lands, where, as shown in the sections of Pl. XII, it is thickly covered by the later Tertiary deposits. North of Pine Ridge it has been deeply eroded, and beyond a narrow zone of outcrops of the underlying Chadron beds the Pierre clay succeeds as the surface formation. There are extensive exposures of the Brule clay in the northern face of Scotts Bluff, where, from the base of the overlying Gering beds to the river, there is a vertical interval of 500 feet of continuous outcrop, and

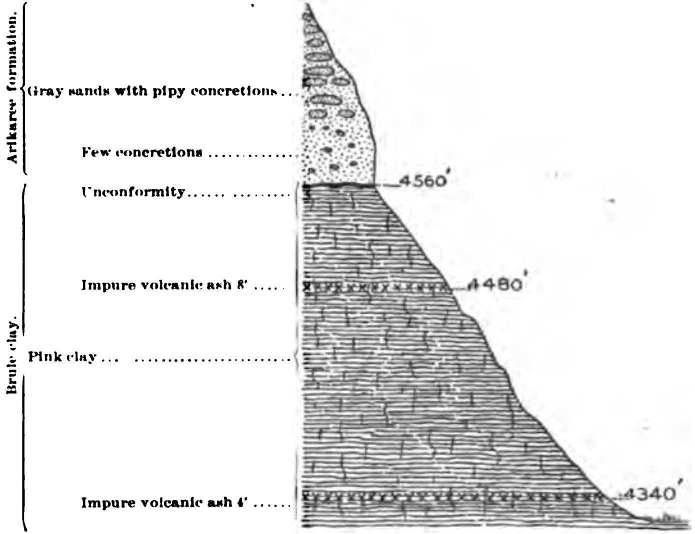


FIG. 17.—Section in vicinity of Funnel Rock, 1 mile north of Ashford, Nebr.

the formation has a small additional thickness below the level of the river. (See Pls. XXX and XXXI.) Along the northern front of Pine Ridge the formation averages 600 feet in thickness, but beginning near Crawford it gradually thins to the east to about 350 feet in the vicinity of Chadron. In Round Top, just west of Adelia, there are 655 feet of Brule beds.

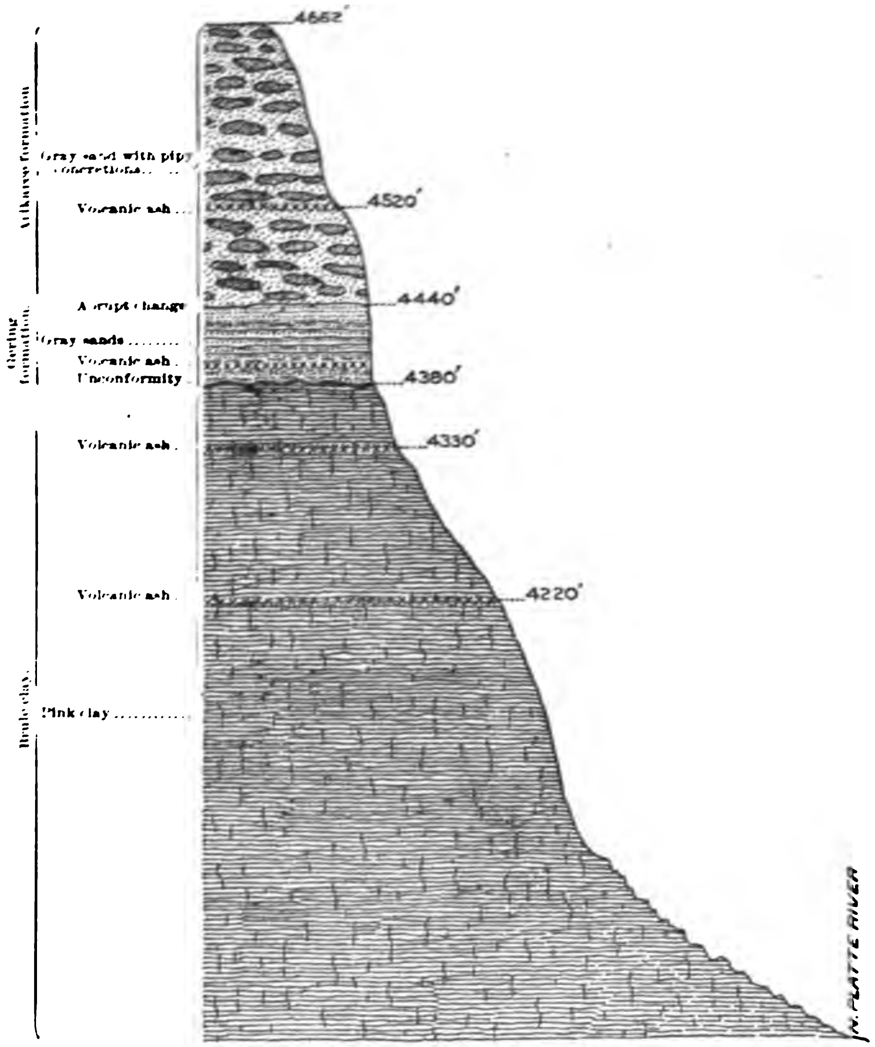
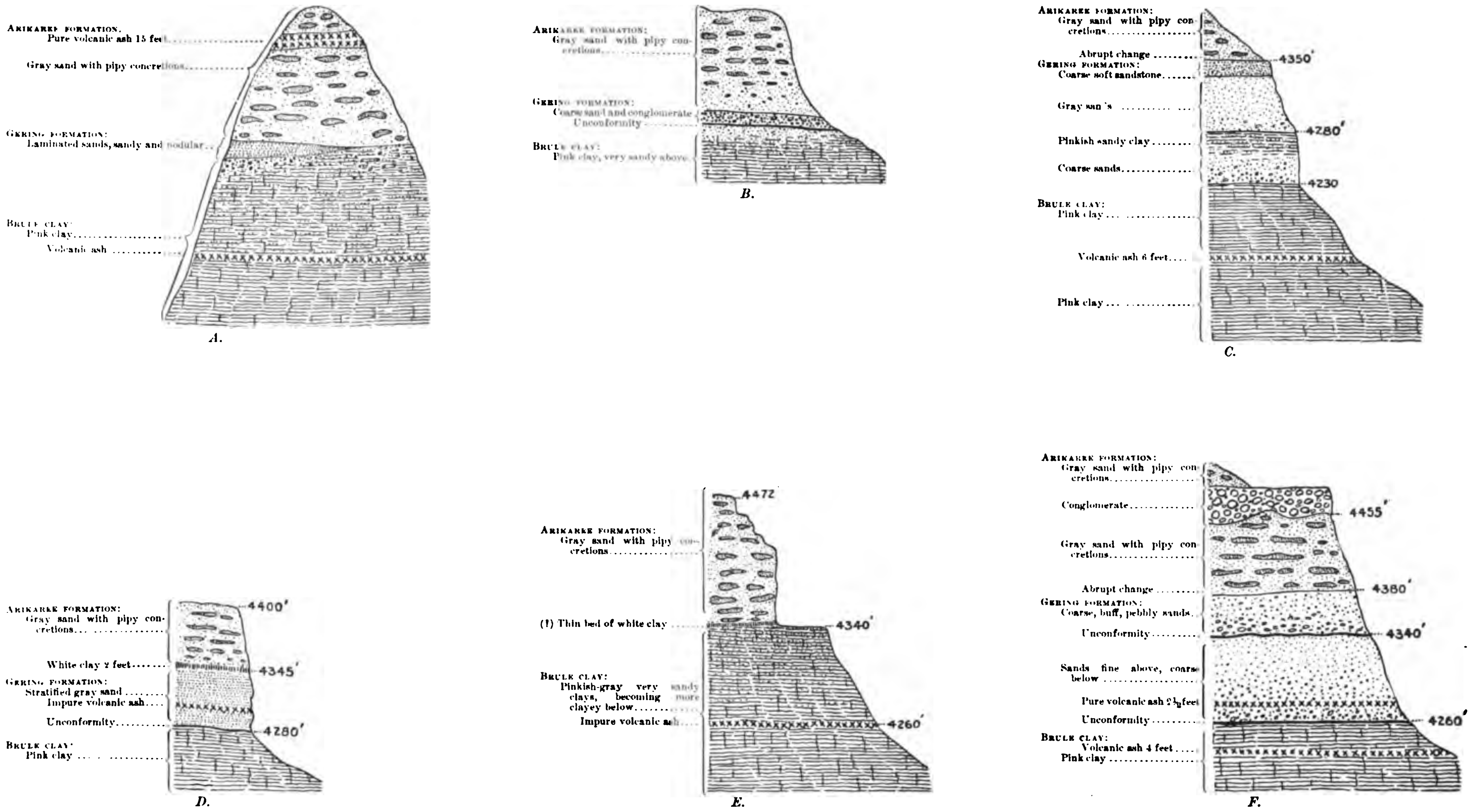


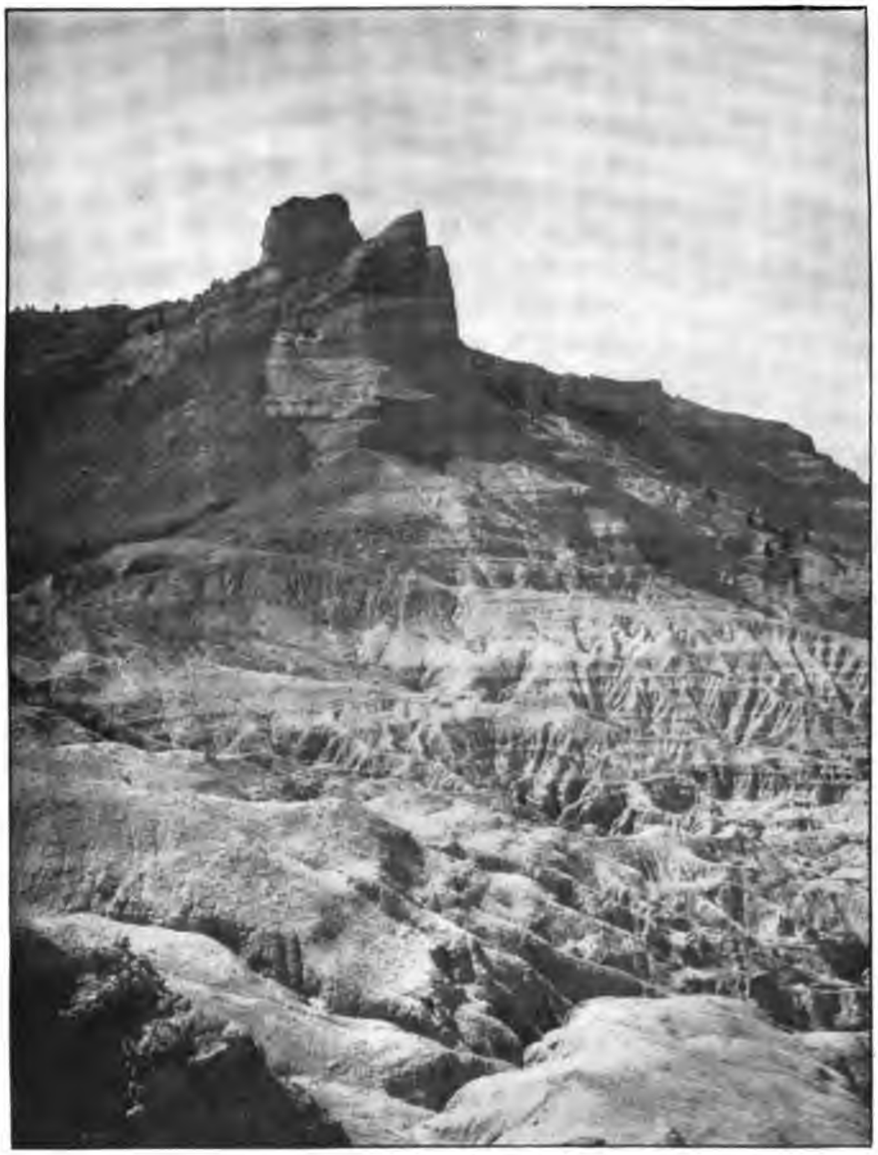
FIG. 18.—Section of north face of Scotts Bluff.

In the region southeast of Gering the Brule formation contains a bed of coarse material which appears to extend several miles. It consists of coarse, cross-bedded sand and conglomerate lying about 120 feet below the top of the formation. The thickness varies from 10 to 80 feet, the thickest portion appearing in canyons and buttes 5 to 6 miles south of Gering. The relations in this vicinity are illustrated in fig. 9. (p. 32),



SECTIONS OF EXPOSURES SHOWING THE RELATIONS OF GERING AND ASSOCIATED FORMATIONS SOUTH AND SOUTHWEST OF LARISSA, NEBR.

A, 2½ miles west-southwest of Larisssa; *B*, 3 miles southwest of Larissa; *C*, 2½ miles south-southwest of Larissa; *D*, 2 miles west of Castle Rock, Banner County; *E*, at Castle Rock, Banner County; *F*, 3 miles south of Larissa.



NORTH FACE OF SCOTTS BLUFF.

Brule clay overlain by Gering and Arikaree formations

and one of the finest exposures is shown in Pl. XXXII, *B*. There are other exposures north of Larissa and northeast of Chimney and Castle rocks, as shown in sections *A* and *D* of Pl. XXVII. In the area near Larissa and south of Gering there is near its base a thin bed of very compact limestone, which again outcrops north of Sunflower.

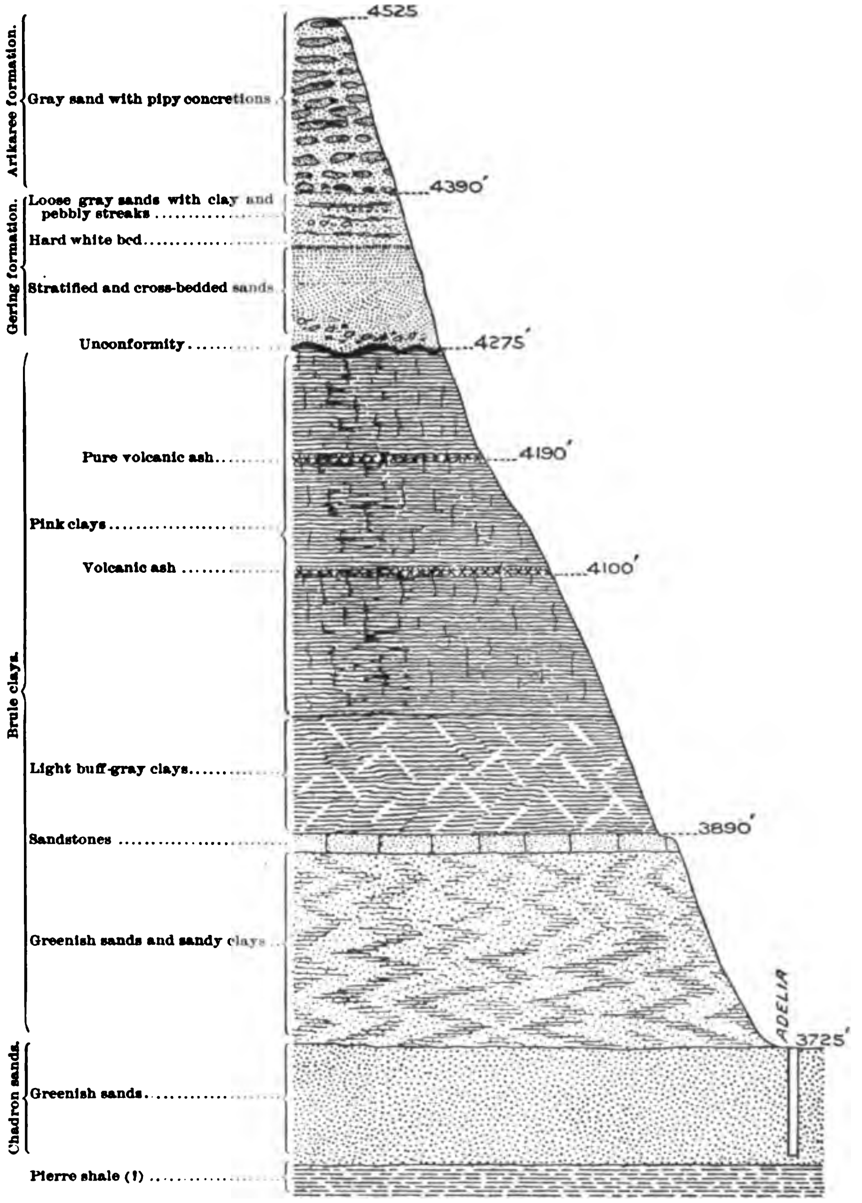


FIG. 19.—Section from Round Top to Adelia station, Sioux County, Nebr.

In the badlands about Adelia station on the Burlington and Missouri River Railroad there are extensive exposures of the Brule and associated formations. (See Pls. XXXIII and XXXIV and fig. 19.)

This section closely resembles the typical section in the Big Bad Lands in South Dakota, but appears to include some higher beds. The alternate greenish and pinkish clays with brown nodular layers lying on the Chadron sands are similar to the Oreodon series and yield many of the same mammalian remains. The sandstone next above probably represents the Metamynodon series, and in it was found a fragment of a tooth, probably of *Metamynodon*. The overlying clays can be less definitely correlated, especially those toward the top, which I believe are higher than the highest beds represented in the Big Bad Lands. They contain two beds of volcanic ash, the upper one 12 feet thick, of nearly pure material, in flat, glassy scales, not so vesicular as usual. Along the eastern extension of Pine Ridge the intermediate beds, those extending from 4,000 to 3,725 feet in the Round Top section, soon thin out, and the Chadron formation is overlain by the flesh-colored clay, with its volcanic ash layer near the top. A section at Chadron is given in fig. 20.

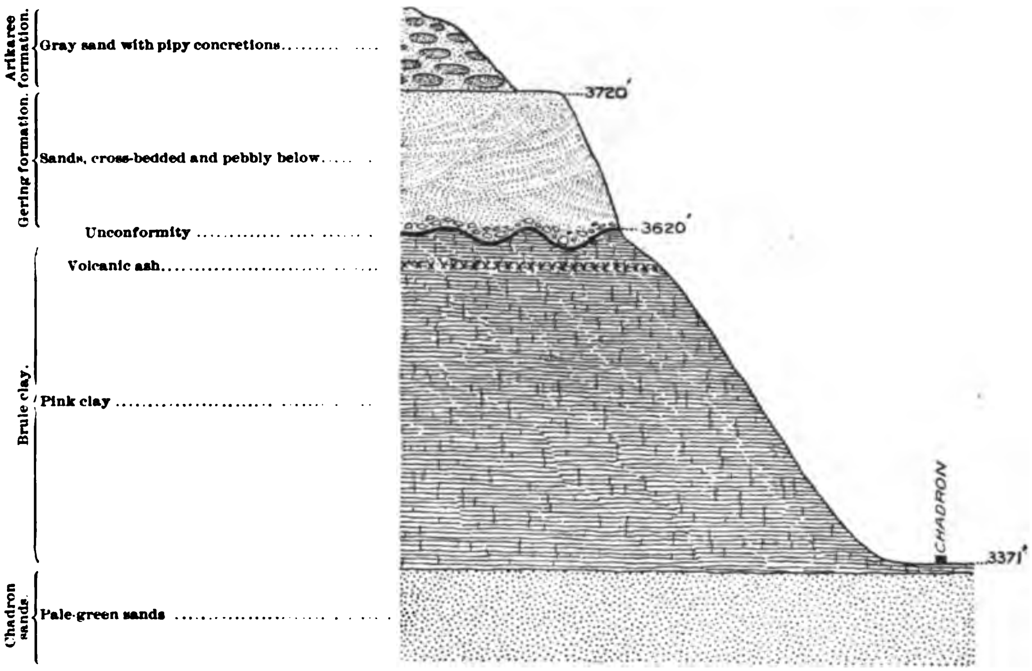
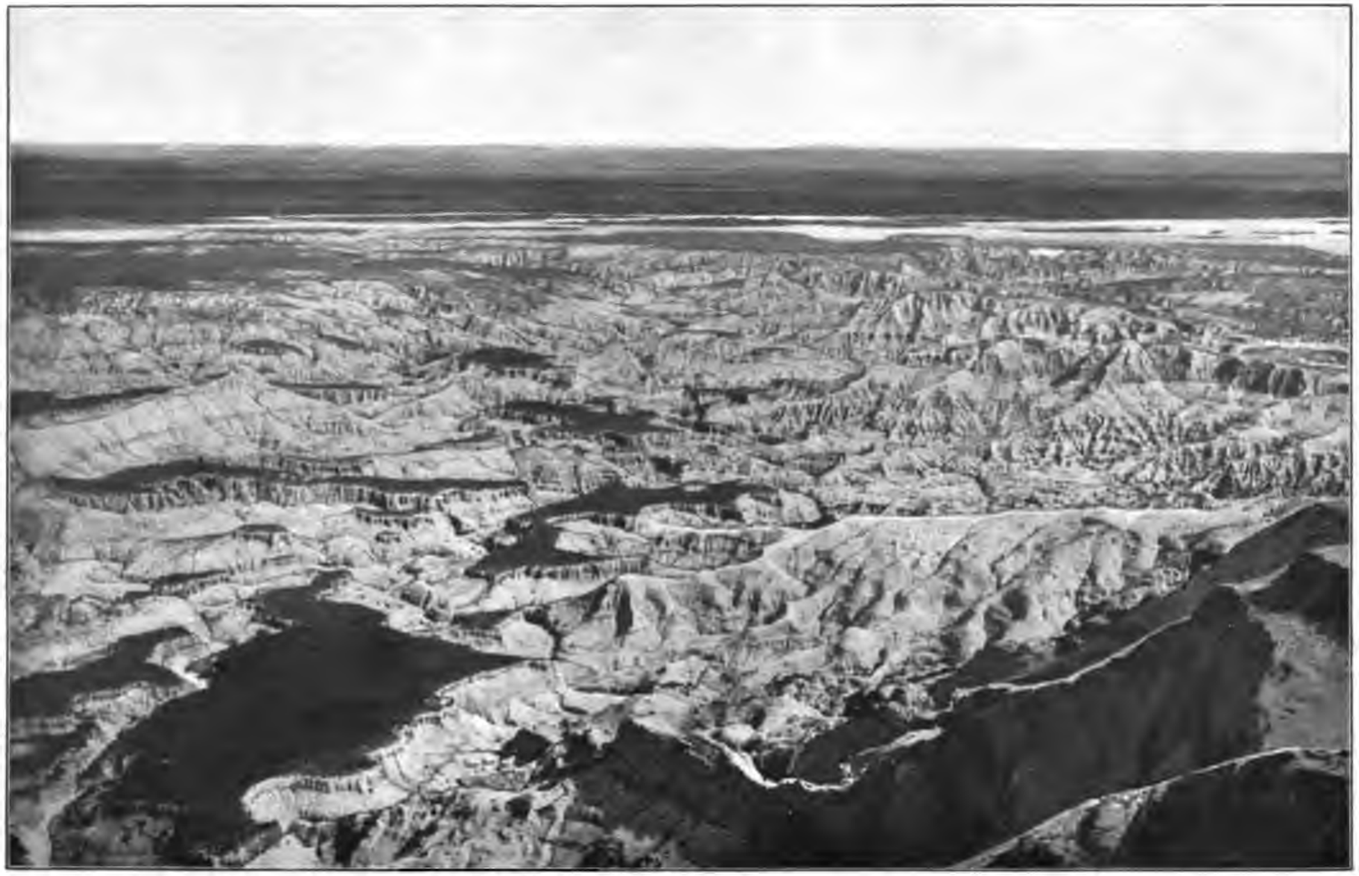


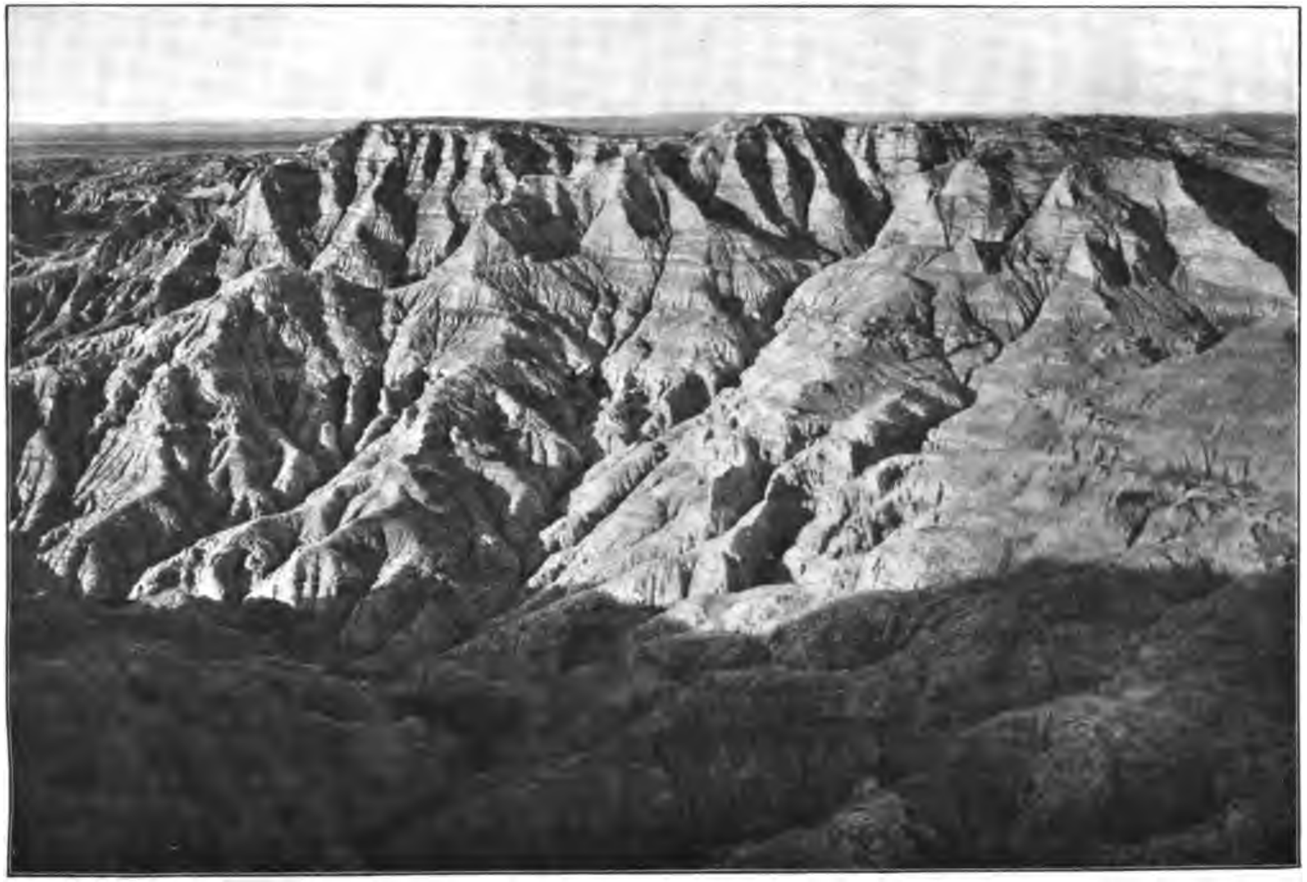
FIG. 20.—Section at Chadron, Nebr.

CHADRON FORMATION.

This basal formation of the Tertiary series outcrops in a narrow zone along the lower slopes north of Pine Ridge, just outside the margin of the overlying Brule



BADLANDS AT FOOT OF SCOTTS BLUFF; GENERAL VIEW.



BADLANDS AT FOOT OF SCOTTS BLUFF; NEAR VIEW.

clays. There is also a small area of outcrop in the valley of North Platte River in the vicinity of Caldwell and Mitchell. The deposits have heretofore been known as the "Titanotherium beds," from the frequent occurrence of remains of several species of a large mammal which has been named *Titanotherium*. As the large bones and peculiar teeth of this animal are very distinctive features, an illustration of a skeleton is reproduced in Pl. XXXV. The predominant material of the formation is sandy clay of light greenish-gray color, usually with coarser beds at the bottom, including deposits of gravels often several feet thick. The beds above these gravels are often of bright dark-red color, notably in the region about Adelia. The thickness of the formation varies from 30 to 60 feet in the outcrops along the foot of Pine Ridge. It thickens considerably in the vicinity of Adelia, where there are included some masses of dark-gray and buff sandstone of coarse texture. At many points around its outer margin the Chadron sands may be seen lying on the irregular, black, or generally rusty surface of the Pierre shale.

LARAMIE FORMATION.

The Laramie formation is exposed in an area of considerable extent in Goshen Hole, which extends for a short distance eastward into Nebraska on the north side of Horse Creek west of Caldwell and on a branch of that creek 5 miles southwest of Caldwell. The rock is a soft greenish-buff to brownish sandstone. Its surface is irregular; to the north it is overlain by Chadron beds and to the south it rises into the base of the Brule clays. Doubtless it extends for some distance east, but its eastern margin was not ascertained.

PIERRE CLAY.

The entire region to which this report relates is underlain by the Pierre clay, a thick mass of dark-colored clays or shales constituting the upper member of the Cretaceous formations in some portions of the Plains. Possibly under the southwest corner of Nebraska the Tertiary formations are underlain by the edge of the Laramie formation—a series of sandstones higher in the Cretaceous—but of this there is at present no evidence. The Pierre shale outcrops in the northern portion of Sioux and Dawes counties, as shown in Pl. XI. The surface of the formation rises somewhat with the general upward slope of its beds toward the Black Hills uplift, and it is exposed by the erosion which has removed the Tertiary formations over the lowlands extending from the valleys of White River and Hat Creek to the foot of the Black Hills. The dark shale gives rise to a rolling region of scant vegetation and poor water supply. Exposures are frequent, and the dark-yellow or rusty surfaces due to the oxidation of the iron pyrites in the shale are characteristic features of the area.

Distinctive fossils of numerous marine mulluscan species are abundant in the

Pierre clay. The fossils are often preserved in concretions of gray siliceous matter of lenticular form, which abound in the upper portion of the formation. The precise thickness of the Pierre shales is not known, but it probably exceeds 1,200 feet.

NIOBRARA LIMESTONE.

The Pierre shale is underlain by the Niobrara limestone, but this formation does not reach the surface in the portion of Nebraska west of the one hundred and third meridian. As, however, it would be reached by deep borings for artesian water, some of its characteristics should be pointed out. Its thickness is about 50 feet. It consists mainly of massive dark-gray chalk or soft limestone, which weathers to a buff or light-cream color when exposed to the atmosphere. The formation can be readily recognized by the very distinctive fossil *Ostrea congesta*, which is nearly always present in abundance in thin, hard layers. In order to aid the well driller in identifying this formation in borings, an illustration of this fossil is introduced in Pl. XXXVI.

BENTON FORMATION.

Underlying the Niobrara limestone and abruptly separated from it are the Benton shales, which have a thickness of 1,500 feet. They contain thin layers of sandstone and limestone; one of the latter, about 900 feet above the Dakota sandstone, is filled with the *Inoceramus* shown in Pl. XXXVI. The formation lies far below the surface along the South Dakota line, but outcrops extensively in the vicinity of Edgemont, having the relations shown in fig. 21.

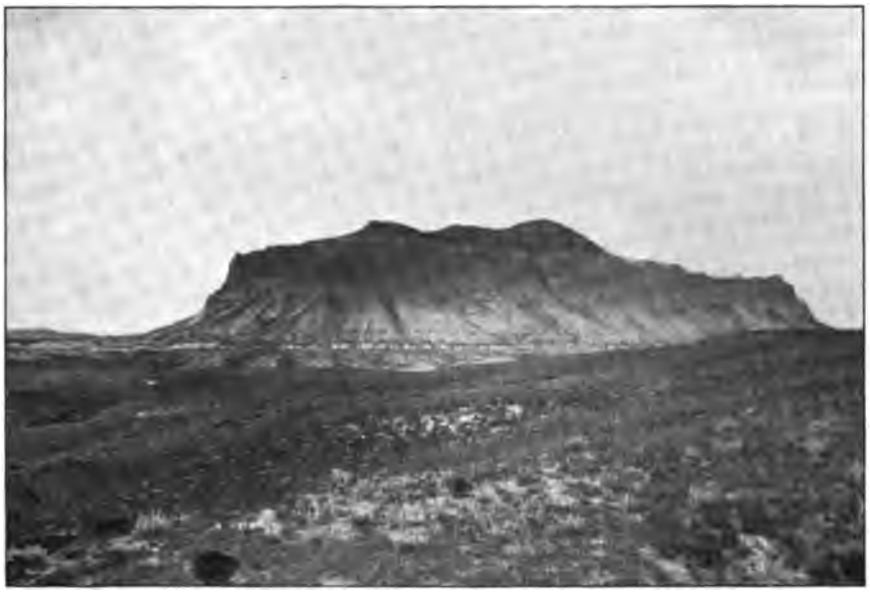
DAKOTA SANDSTONE.

This is the water-bearing sandstone of South Dakota and northeastern Nebraska, and it underlies all the region to which this report relates. It is a gray or brownish sand rock, occurring in thick beds, with intercalated lenses of shale or clay and occasionally thin seams of coal. Its relations in the northern part of the area are shown in fig. 21 and Pl. X. Its lower beds are of Lower Cretaceous age.

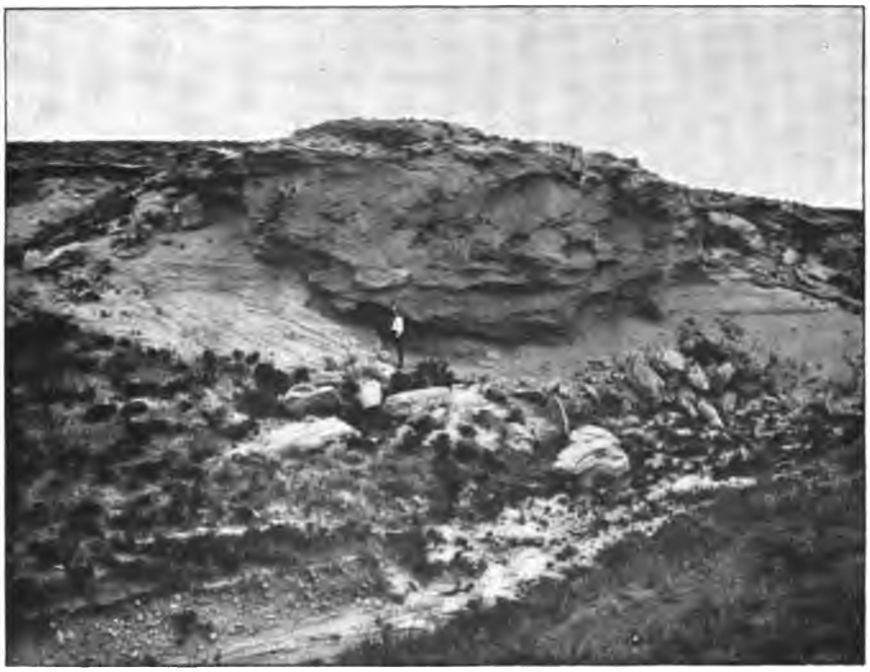
VOLCANIC ASH.

In studying the geology of this region it was found that several formations contained extensive deposits of volcanic ash. Some of this material was found in the Chadron formation; two very widespread beds occur in the Brule clay; lenses of the ash are often included in the Gering formation; and there is a general admixture of ash as well as a number of thick beds of it in the Arikaree formation. So far as observed it is rare in the Ogalalla formation. In the central and eastern portion of the State it occurs mainly in the lower portion of the loess.

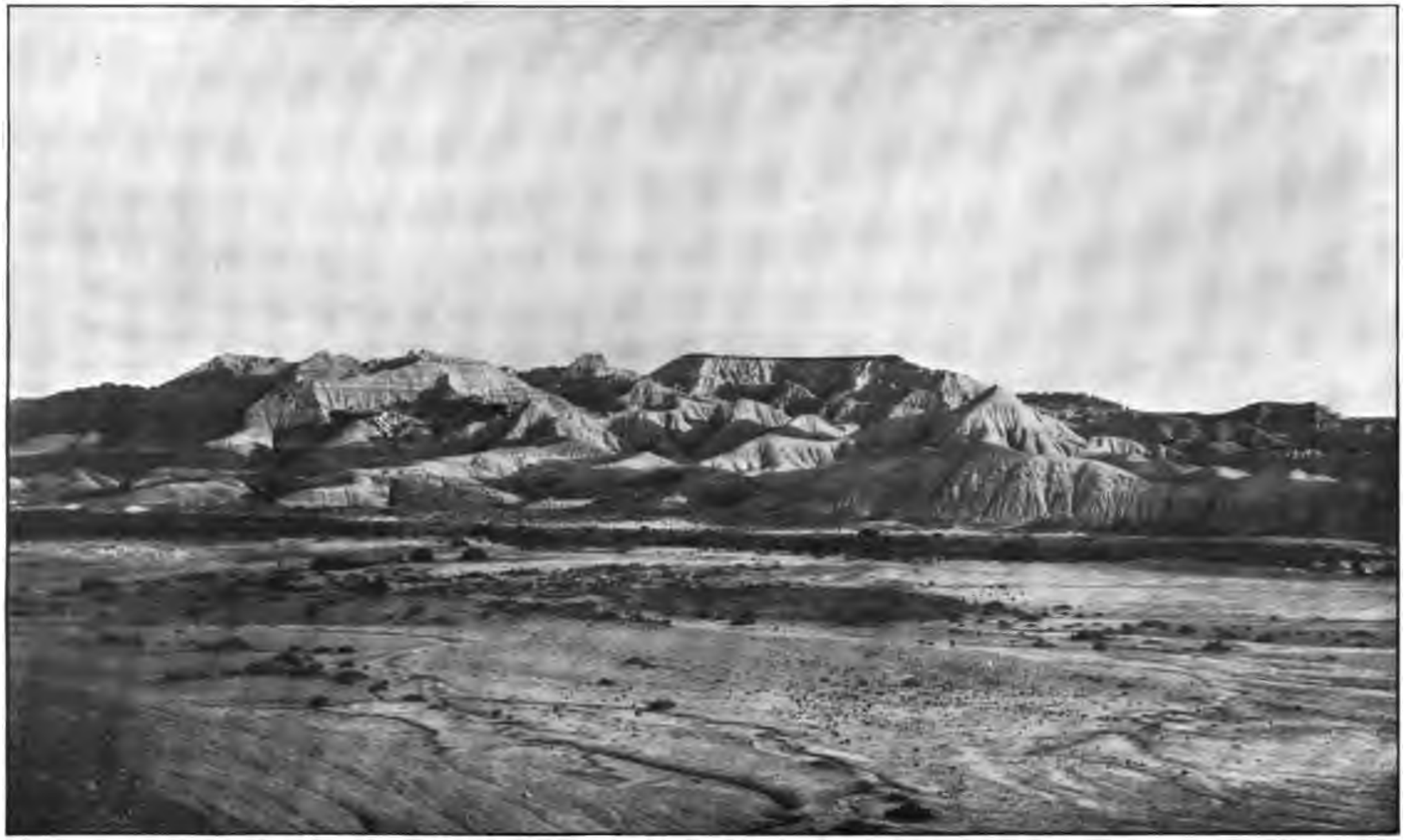
The ash deposits are usually more or less mixed with clay or sand, but there are many beds in which the deposits are thick and pure. They promise to have considerable commercial value, mainly for polishing powder.



A. CASTLE ROCK, SCOTTS BLUFF COUNTY, NEBR., FROM THE EAST, SHOWING BED OF VOLCANIC ASH NEAR THE FOOT OF THE SLOPE.



B. LENS OF COARSE MATERIAL IN BRULE FORMATION, 4 MILES SOUTH OF GERING, NEBR.



BADLANDS OF BRULE FORMATION, WEST OF ADELIA, SIOUX COUNTY, NEBR.; LOOKING NORTHWEST.

(From photograph by E. H. Barbour, University of Nebraska.)

The most persistent layer is in the Brule clay, at an average distance of about 70 feet below its top, in the ridge next south of North Platte River. This bed is shown in Pl. XXIV and Pl. XXXII, *A*. A lower bed, usually much less pure, occurs from 80 to 100 feet below the upper one. On the north side of Pine Ridge these two horizons are recognized in some of the higher beds in Sowbelly Canyon and at Round Top and near Chadron, as shown in figs. 19 and 20. The volcanic ash occurring in the Gering formation is usually restricted in extent and variable in relations. It is, however, often exceptionally pure.

The Arikaree formation contains a sprinkling of ash almost throughout its extent. In some of the bluffs southwest of Gering a thickness of 100 feet of sandy clays of this formation was observed, which contains a fairly large proportion of ash. In the high isolated butte 3 miles west by south from Larissa there is a 15-foot bed of nearly pure ash, with pipy concretions scattered through it, in the midst of the Arikaree formation. In Wildcat Mountain beds of ash were found at intervals nearly to the cap of Ogalalla formation. The formation contains a large admixture of ash in the vicinity of Fort Robinson and again at Round Top, near Adelia, as shown in fig. 19 (p. 39).

The ash in these formations was probably derived from volcanoes in the Rocky Mountain region, for there is no evidence of Tertiary volcanoes in the vicinity. The ash was undoubtedly borne on the winds and deposited in the waters which laid down the several Tertiary formations. When the ash came in large volume, or there was very little other sediment, pure deposits resulted; but ordinarily there was considerable admixture of the fine sand and clay.

UNDERGROUND WATERS.

GENERAL CONDITIONS.

The relations of underground waters in this region present a variety of features. In many localities there are large supplies at moderate depths, and in other places the amount of waters in reach of the average farmer is so small as seriously to interfere with the settlement of areas of considerable extent. This has been particularly the case where large volumes of water were needed for cattle. The greatest difficulty in obtaining water has been in the area of the Brule clay back from the rivers and in the region underlain by Pierre clay. In the flats adjoining the river in Platte Valley and in Lodgepole Valley water supplies are usually obtained in wells from 10 to 40 feet in depth. On the table-lands on both sides of Lodgepole Valley waters are obtainable in large volume from wells from 150 to 300 feet deep, the depth increasing gradually westward. In Niobrara Valley supplies of water are obtained from shallow wells in the narrow strip of alluvial deposits near the river, and farther back on the table-land plenty of water is found at depths varying from 50 and 100 feet on the lower slopes to 300 feet in some of the highest areas to the northwest. In the sand hills water accumulates in basins at moderate distances below the surface, so that shallow wells ordinarily obtain satisfactory supplies.

Along the outer edge of the Brule clay area north of Pine Ridge water is usually found in the underlying Chadron sands. In Pl. XXXVII are shown the depths to water supplies in the western Nebraska region, based on observations of the water level in wells and springs and determinations of the geologic relations of the water-bearing formations.

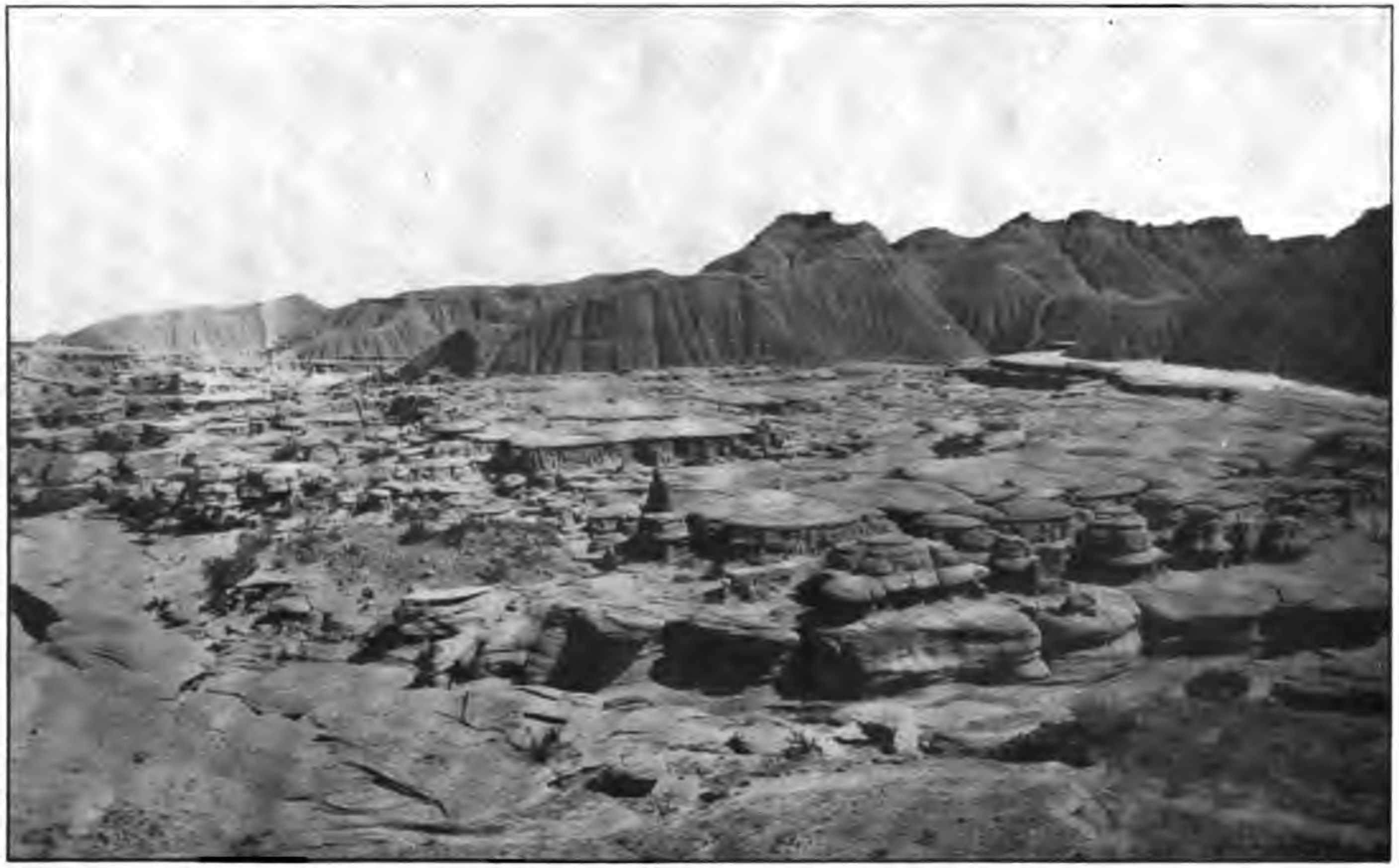
WATER HORIZONS.

In the alluvial formations along Platte, Niobrara, and White rivers and Lodgepole, Pumpkinseed, Snake, and Hat creeks, and some of their branches, the water supply constitutes an underflow. Along the Platte this underflow is of large volume, but in some areas the water is somewhat alkaline. In the Pumpkinseed Valley at some localities, and in the greater portion of the White River and Hat Creek valleys, where they traverse the Pierre shales, these water supplies are often unsatisfactory both in quantity and in quality.

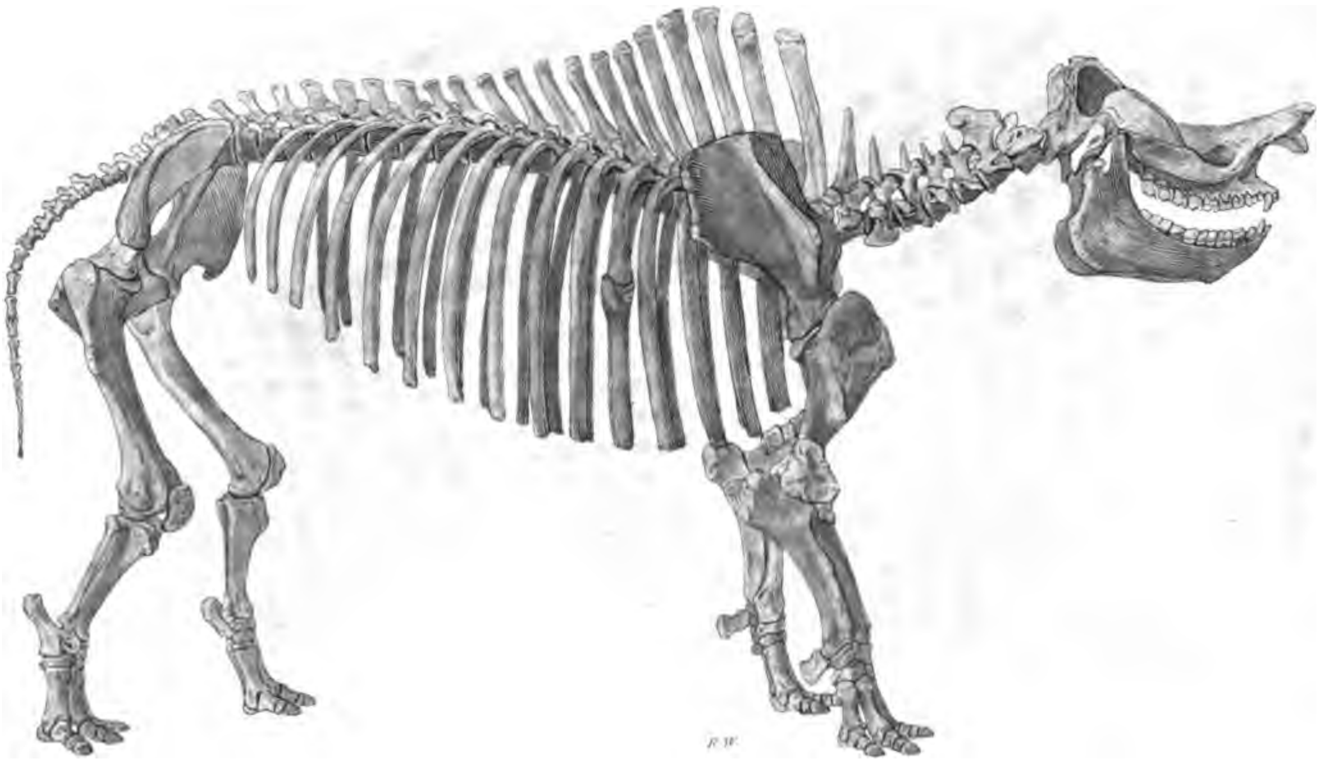
The next horizon is at the base of the Ogalalla formation, which supplies water for many wells on the table-lands on both sides of the Lodgepole Valley at depths varying from 100 to 300 feet. The volume of water appears to be large at nearly all localities. At some places the waters are obtained high up in the formation, but the principal supplies are in the basal beds. At many points along the northern margin of the table-land these waters flow out into the canyons as springs of greater or less force, of which the most noteworthy are those on Greenwood, Middle, Hackberry, and Bighorn creeks, in Lawrence Fork Canyon, and at Gabe, Long, and Duggers springs.

The Arikaree formation is a general reservoir for water, which is nearly everywhere available in the table-lands lying between the valley of North Platte River and the crest of Pine Ridge. In some areas it is necessary to sink wells to the base of the formation, where the materials are somewhat coarser than those higher up, but ordinarily the higher beds yield satisfactory supplies. These waters flow out at the surface in springs of greater or less magnitude in many canyons along the front of Pine Ridge; at a few widely scattered points in the Niobrara Valley, notably at Coyote Spring and at Royville; in the Snake Creek Valley, at Point of Rock Spring and Mud Spring; and along the north slope of the Platte Valley, at the spring near the head of Sheep Creek and the springs near the heads of Red Willow and Indian creeks.

The Gering formation contains water throughout its area, but it does not appear to be reached by many wells. Numerous springs on the ridge south of North Platte River flow from this formation at the surface of the Brule clay. Along the front of Pine Ridge there are a number of springs which flow out of these beds, and possibly



"TOADSTOOL PARK" IN BADLANDS NORTHWEST OF ADELIA, SIOUX COUNTY, NEBR. (BRULE FORMATION).



TITANOTHERIUM ROBUSTUM.

One twenty-third ($\frac{1}{23}$) natural size.

some of the deeper wells on the summit of Pine Ridge obtain their water from this horizon, but ordinarily ample supply is reached at a less depth in the overlying Arikaree formation.

The Brule clay immediately underlies a wide area of the high slopes of the North Platte and Pumpkinseed valleys and yields water supplies to many wells. It is known as "hardpan" to the well drillers. In most cases, however, the volume of the water is small, and its quality is often unsatisfactory. Numerous abandoned houses in these valleys usually indicate that prospective settlers have been unable to obtain water supplies at moderate depths from the Brule clay. Where water occurs it is in crevices and fissures, which traverse the clay at moderately frequent intervals, but the volume of water depends on many factors, and there is seldom a good chance to obtain a large supply. In the area north of Pine Ridge the wells usually penetrate through the Brule clay into the underlying Chadron sands, which almost invariably contain fairly large volumes of water. It is a source of supply to a number of farmers and ranches. The water is not always of satisfactory quality, and in the wells at Adelia and Crawford it has been found unsuitable for locomotives. This formation underlies the Brule clays in the Platte and Pumpkinseed valleys, and probably would often yield water there to wells a few hundred feet in depth. Some years ago a well was sunk at Gering to a depth of 331 feet, which obtained a promising flow of water, probably from the Laramie sandstone, which underlies the Chadron formation. Owing to the small size of the pipe and to accidents in boring, the well did not continue to flow, and clogged up so that it was a failure. As water supplies are particularly scant in the region about Gering and in the valleys to the south, it is very unfortunate that this boring was not given a fair trial. At Harrisburg, on the south slope of Pumpkinseed Valley, a boring has recently been made to a depth of 790 feet without obtaining a flow. Judging from the small samples of the borings which were seen, the well passed through the Chadron sands and entered the Laramie formation for several hundred feet, but it did not obtain a sufficient supply of water. It is known that the edge of the Laramie formation extends into southwestern Nebraska under the Chadron sands, and it should be expected to yield a water supply that would rise to an altitude of about 4,500 feet. In the underlying Pierre shale there are no chances for water. In the area in which this formation is at the surface, in northern Sioux and Dawes counties, great difficulty has been experienced in obtaining water supplies for local use, and the water found has generally proved to be of unsatisfactory quality.

DEEP-SEATED WATERS.

In the older formations which underlie Nebraska there are widespread sheets of permeable deposits which carry large volumes of water. In the region to the west these deposits lie at great depth, and many of the higher lands are probably above the level to which the waters would rise to afford surface flows. Owing to the failure of any boring in the central and western portion of the State to reach the deep-seated water-bearing beds, there is lack of definite knowledge as to their depth, but there can be no doubt of their presence. The section constituting Pl. X illustrates the general relations of the two principal deep water-bearing formations—the Dakota sandstone and the Carboniferous and underlying limestones. In eastern South Dakota the Dakota sandstone yields to many wells large volumes of excellent water under high pressure. In eastern Nebraska, where the formation approaches the surface, it is also the source of water supply, at first to wells of moderate depth and then to innumerable springs. The Carboniferous and underlying formations yield water to numerous wells between 650 and 1,500 feet deep in eastern Nebraska and Iowa. These waters pass into the formations along the foothills of the Black Hills and the Rocky Mountains at altitudes of from 3,000 to 6,000 feet in greater part, and have considerable pressure and head far to the east. This pressure and head, however, gradually decrease as the formations reach or approach the surface, the water then being free to escape. The waters in the Dakota sandstone lose their head entirely in eastern Nebraska, where the formation outcrops. The waters in the underlying Carboniferous limestones and older formations retain a moderate amount of head throughout Nebraska. Some of the factors bearing on the occurrence of these deep underground waters are shown in Pl. XXXVIII, and in Pl. XXXIX are shown some of the conditions of occurrence of the waters in the Carboniferous and underlying formations in the vicinity of Omaha, Nebr. It will be seen in Pl. XXXIX that the head is relatively constant near 1,100 feet above sea level over a wide area about Omaha, but there is a slight rise to the west even in a few miles. At Lincoln it is 1,210 feet above sea level. The increase of head and pressure to the west and northwest is gradual, for the distance is great, but the amount becomes large as the Black Hills and Rocky Mountain zones of intake are approached. In Pl. XXXVIII figures are given showing the altitudes along these zones and along

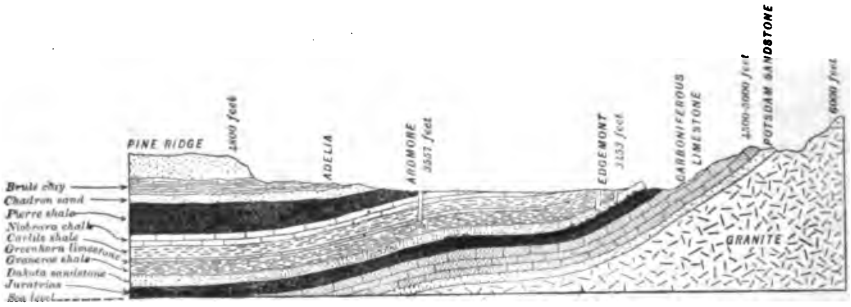
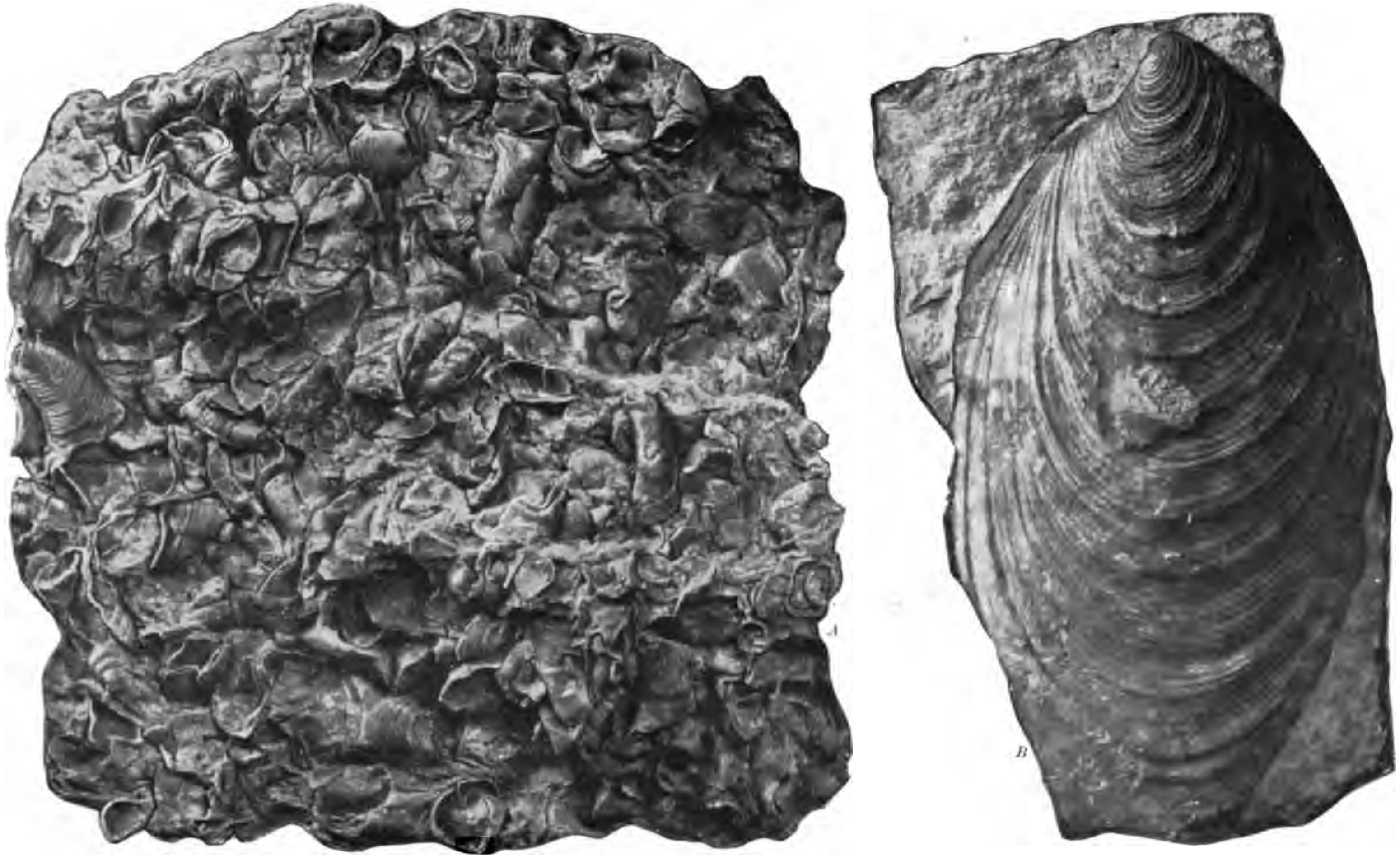


FIG. 21.—Section from Black Hills to Pine Ridge.



TYPICAL FOSSILS OF NIOBRARA CHALK AND GREENHORN LIMESTONE.

A, Ostrea congesta Conrad; *B*, Inoceramus labiatus Schloth.

the outcrop areas east, which will afford some idea of the head to be expected in the intermediate region. In the diagram, fig. 22, there is shown a piece of physical apparatus which illustrates the gradient of head between a leak on the one hand and the source of pressure on the other, representing closely the relations which have been found to exist in the South Dakota artesian basin and probably prevail in a measure also in central and eastern Nebraska, where the head of the deeper-seated waters diminishes eastward.

Data are not sufficiently definite as yet for a precise determination of this gradient of head across western Nebraska, but it is apparent that in some of the valleys westward the head is probably higher than the altitude of the land, so that there are prospects for surface flows.

In order to reach the deep-seated waters in western Nebraska it is necessary to penetrate the Tertiary formations, the Pierre clay, the Niobrara limestone, and the Benton shale, to the Dakota sandstone, which should be expected to yield a large supply of excellent water. An attempt was made to reach this horizon in a deep boring at Chadron some years ago. A depth of 1,100 feet was attained, when the boring was abandoned owing to great difficulty in penetrating the Pierre shale. More recently an attempt has been made at Ardmore by the Burlington and Missouri River Railroad, which attained a depth of 1,500 feet apparently without reaching the bottom of the Upper Cretaceous shales. These shales can be penetrated only by skillful well drillers, and it is necessary to begin with casing 12 or 14 inches in diameter at the top, as the size will have to be reduced occasionally as the boring progresses. The depth to the Dakota sandstone at Crawford will probably prove to be 2,000 feet, and in the valley of North Platte River the amount may be somewhat more. There is possibility of obtaining a flow in these localities, although the altitude is somewhat greater than that of the Dakota sandstone outcrops along the southern margin of the Black Hills. It is to be expected that the pressure of water in the Dakota sandstone will increase to the southwest, in the direction of the Rocky Mountains.

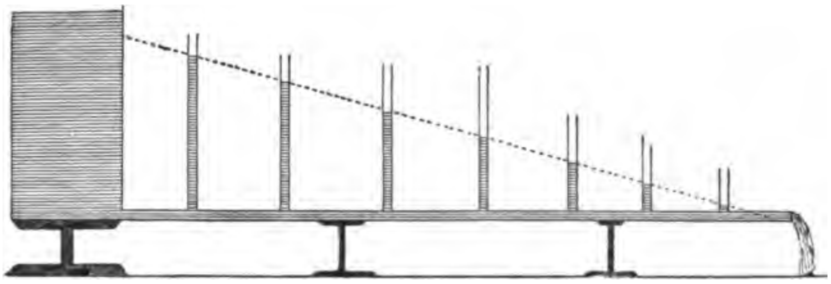


FIG. 22.—Diagram of apparatus illustrating the declivity of head of liquids flowing from a reservoir

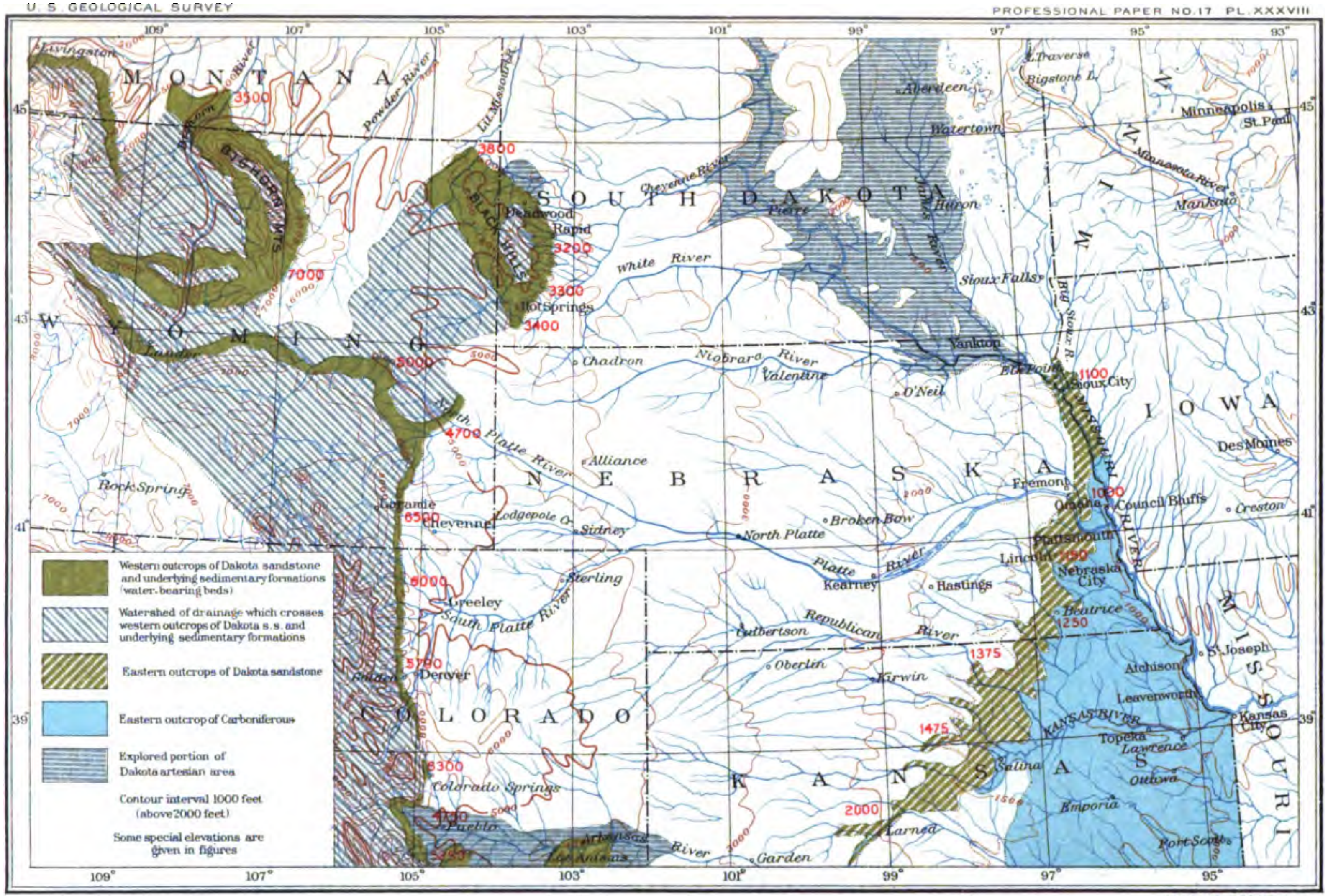
Underlying the Dakota sandstone, with a series of gray and red sandstones intervening, are the limestones of Carboniferous age, which contain water in considerable volume and with somewhat greater head than the waters in the Dakota sandstone. These are the same beds as those yielding flows in the Missouri Valley about Omaha, and there is fair reason to believe that they would prove a satisfactory source of water supply in other portions of Nebraska.

SPRINGS.

Several of the water-bearing formations reach the surface along the valley slopes, where their outcrop is marked by the presence of springs. The locations of the greater number of these springs are shown in Pl. XXXVII. The Arikaree formation in the high area north of the valley of Platte River supplies numerous springs, notably along the northern front of Pine Ridge. The basal beds of the Ogalalla formation also yield springs in the canyons south of the valley of Pumpkinseed Creek and along both sides of the valley of Lodgepole Creek. The most extensive series of springs is along the north front of Pine Ridge, at the base of the Arikaree formation and from the underlying Gering sands. All of the larger canyons contain springs of considerable volume, often at a succession of levels. Sowbelly Canyon is particularly favored in this respect, but the other valleys, from Jim Creek to Chadron Creek, also have good water supplies from these sources. Even on Round Top there is a fine spring just above the top of the Brule clay badlands. In the Brule clay area springs are rare and the volume of water is small. In the underlying Chadron beds there is more or less water at all points, which gives rise to seeps and springs along the outcrop zone of these beds north of Pine Ridge. In the Pierre shale region, next northward, springs are rare, superficial in origin, small in volume, and usually highly mineralized with iron, gypsum, or alkalies.

Along the Niobrara Valley there are occasional springs, mainly in the immediate vicinity of the river. Whistle Creek practically heads in Coyote Springs, at an altitude of 4,520 feet, in the center of T. 27, R. 53. The more important springs along the northern side of the valley of Platte River are East Spring, Spottedtail Spring, Wind Spring, Winter Spring, the springs near the head of Sheep Creek, and those at the headwaters of Red Willow and Indian creeks. They are derived from the lower portions of the Arikaree formation, except the Spottedtail and Winter springs, which emerge from alluvium in valley bottoms.

In the ridge between Platte River and Pumpkinseed Creek there are numerous small springs at the heads of some of the larger canyons which yield excellent water. Their distribution is shown in Pl. XXXVII. The water is derived mainly from the Gering sands at their contact with the Brule clay.



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CONTOUR MAP OF UPPER MISSOURI RIVER REGION

SHOWING FACTORS BEARING ON PROSPECTS FOR DEEP UNDERGROUND WATERS

BY N. H. DARTON 1898

Scale

50 25 0 50 100 150 200 250 300 miles

The Pumpkinseed Valley is excavated entirely in the Brule clay, and its lower springs are derived from the alluvial deposits in the valley. This is also the case with springs on Willow Creek and Middle Creek. In the canyons along the north front of the high table-land south of Pumpkinseed Creek there are numerous springs, which yield moderate amounts of water, mainly from the base of the Arikaree formation, and, where this deposit is absent, from the base of the Ogalalla formation. These springs are known as Gabe Spring and Long Spring southwest of Harrisburg and Duggers Spring south of Courthouse Rock.

There are a number of springs along the valley of Lawrence Fork, notably one 2 miles south of Redington, which yields a large flow of excellent water. This flow, however, sinks east of Redington and reaches Pumpkinseed Creek underground.

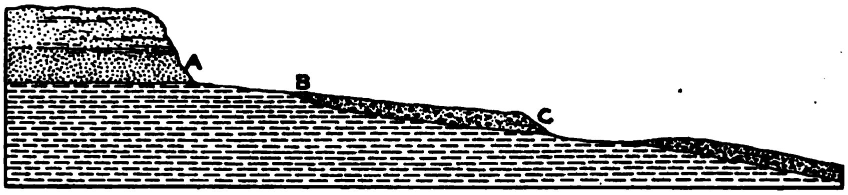


FIG. 23.—Ideal section to illustrate some characteristic features of springs in western Nebraska.

In Lodgepole Valley springs are very rare except at points where the creek itself, having sunk into the alluvial materials in the bottom of the valley, comes out again to flow on the surface for some distance. The best-known spring of this creek is at the "Spring farm," just east of Bronson. Two small springs in Sidney Draw furnish a moderate amount of water.

The springs in this region generally occur under two conditions, which are illustrated in fig. 23. On the left-hand side of the section there is shown the typical spring flowing out of sands, A, at their surface outcrop in a canyon or at the base of high lands. The water gathers from rainfall at a greater or less distance away and sinks underground into permeable beds, through which it travels to emerge as a spring at lower levels. There are many cases, particularly in arid and semiarid regions, where the volume of a rivulet or stream is so small that after running over the surface for some distance the water will sink into the coarse materials which usually lie in the bottom of a valley, as at B. It may then continue as an underflow and emerge in places as a spring of the type shown at C, in the middle of the section in fig. 23. This occurs frequently in the region, and is the nature of some of the low-level springs above described.

STREAMS.

NORTH PLATTE RIVER.

This stream traverses the central portion of the area and, although it is shallow during the greater portion of the year, carries a relatively large body of water. Its flow is subject to seasonal variations, ranging from a wide, deep torrent in late spring and the first month of summer to a shallow, irregular network of streams flowing among sand bars in the later summer and autumn. It has been estimated that at Gering the North Platte drainage area is 24,340 square miles; at Camp Clarke about 24,830 square miles; and at North Platte 28,517 square miles. The details of river measurements at these three points are given in Water-Supply and Irrigation Paper No. 15, on pages 84, 85, and 86, respectively, and the results of computations of discharge on pages 308 to 310 of Part IV of the Nineteenth Annual Report. Reference should also be made to the data given in Part IV of the Eighteenth Annual Report, on pages 153 to 158, inclusive, and in Bulletin No. 140, on pages 99 to 102.

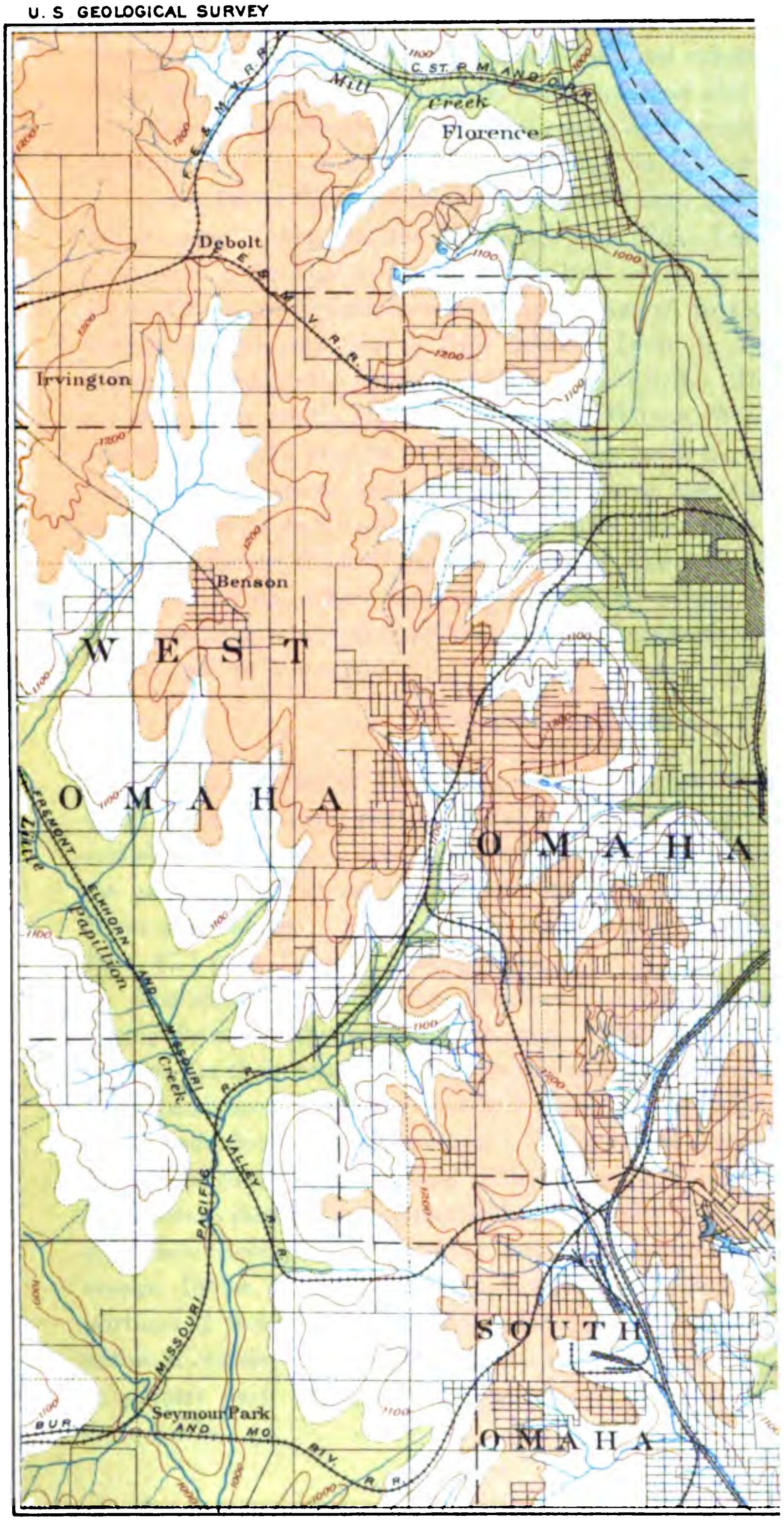
Estimated monthly discharge of North Platte River at Camp Clarke, Nebraska.

Date.	Maximum.	Minimum.	Mean.
1896.	*Second-feet.*	*Second-feet.*	*Second-feet.*
June 28–30	4,100	3,102	3,508
July 1–31	2,386	977	1,554
August 1–31	1,316	628	924
September 1–30	1,186	738	939
October 1–31	1,290	875	1,008
November 1–8	1,238	706	1,091
1897.			
January	2,404	2,042	2,287
February	2,404	1,567	2,253
March	2,223	450	1,299
April	8,390	1,567	3,649
May	10,540	6,885	8,688
June	11,400	4,520	7,401
July	4,305	930	2,147
August	2,042	580	1,066
September	580	400	492
October	580	350	484
November	....	....	[a] 500
December	....	....	[a] 500

[a] Approximate.

A large volume of the water is taken out of the river at intervals in Scotts Bluff and Cheyenne counties by the various irrigation canals, so that the reports at

U. S GEOLOGICAL SURVEY



CONTOUR MAP OF OMAHA AND VICINITY SI

BY N. H. DAR

SCAL

JULIUS BIEN & C

Gering and Camp Clarke do not indicate the total volume of water which enters the State from the west. It should be borne in mind also that under the bed of the river there is considerable thickness of coarse sand containing an underflow of which the volume is far greater than that flowing on the surface in dry weather.

North Platte River receives a number of minor branches between the mouth of Pumpkinseed Creek and the Wyoming line. They head in the high ridge to the south and in the edge of the high table-land on the north. With the exception of Horse Creek, their surface waters do not extend to the river, and some of them usually are entirely dry to their heads. There is, however, generally a small underflow through the coarse materials in their beds. The largest volumes of water are from the north, in Dugout, Indian, Red Willow, Winter, Spottedtail, and Sheep creeks. These all head in living springs high up in the canyons, but the waters run only a short distance and sink into the coarse materials, where their volume as underflows is probably not large. Very little water flows out of the ridge extending from Courthouse Rock to the headwaters of Kiowa Creek, and except in the heads of a few canyons where there are springs the valleys are dry and appear to have but scant underflow. Horse Creek carries a moderate volume of water from some high ridges in Wyoming.

PUMPKINSEED CREEK.

The wide valley of Pumpkinseed Creek is traversed by a small stream which heads in the northwest portion of Banner County, in springs and seeps which gather considerable volume in the vicinity of Ashford. Additional supplies are received to the east, but the stream increases in size very gradually. It enters North Platte River near Lapeer. Some gagings made near its mouth were as follows: July 26, 1894, 17.1 feet; June 28, 1896, 22.2 feet.

The stream has numerous branches, but these contribute only surface water during the more rainy portion of the year. They nearly all have underflows of small volume, for their beds consist of gravels and sands into which the water sinks to the "hardpan" floor, and, moving slowly under ground, adds materially to the volume of the underflow of the main creek. The principal affluent is Lawrence Fork, which contains a considerable volume of water in Ts. 17 and 18, R. 52, but this water finally sinks during the summer and flows underground for 2 miles to join the main creek near Redington. The other branches—Greenwood, Hackberry, and Bighorn creeks, Indian Springs, and Willow Creek—all contain some water in the upper portions of their valleys, but this water sinks into the coarse material of the valleys before it reaches Pumpkinseed Creek. The branches from the north are dry coulées in greater part. They contain water from very small springs in the vicinity of their heads.

LODGEPOLE CREEK.

The waters of Lodgepole Creek rise in Wyoming and, gradually gaining volume, enter Nebraska with a flow which, in August, 1895, was found to be 3.5 cubic feet a second. At about the same time the creek was found to flow 4 cubic feet a second at the north-south line between secs. 34 and 35, T. 15, R. 57. The volume varies greatly from point to point, but there appears to be a good underflow. For portions of its course the entire volume of the stream is diverted into irrigation ditches. In summer the creek becomes perfectly dry from the vicinity of sec. 28, T. 15, R. 54, for about 12 miles, to a point near the south line of sec. 4, T. 14, R. 52, where the water again appears, running 2½ cubic feet a second at first, and then at a dam one-half mile below 4 cubic feet a second. There are in this vicinity many short ditches which take all or the greater portion of the water and leave the creek dry below the dam in the SE. ¼ sec. 14, T. 14, R. 51. It continues dry through sec. 13 and nearly through sec. 19, but near the east line of sec. 19 the water again rises to the surface and flows 2 cubic feet a second for a short distance. Then the creek is dry nearly to sec. 36, T. 14, R. 50, where there is a flow of about one-half a second-foot, which is diverted into irrigation ditches.

All these measurements were made in August, 1895, by Mr. Adna Dobson, as given in the first report of the State board of irrigation for 1895 and 1896. A measurement of the Lodgepole made at Kimball by Mr. Youngfelt on June 26, 1896, indicated 4.5 second-feet.

Several tributaries empty into the valley of Lodgepole Creek, but they do not contain flowing waters except in times of freshet. The principal one is Sidney Draw with its two branches, heading in the high table-land far westward in Kimball County, south of Lodgepole Valley. The branches which empty into Lodgepole Creek from the north head in high table-lands a short distance back and descend to the valley as dry coulées with steep declivities. Some contain underflows from springs which ordinarily do not have sufficient volume to reach the surface.

SNAKE CREEK.

Snake Creek is a stream which heads in the southeast corner of Sioux County, mainly among the sand hills, and flows in a very shallow valley over the table-land north of the valley of North Platte River. It receives waters from various springs, but its flow over the surface is intermittent and the volume of water relatively small. Its principal branch is from the north, known as Point of Rocks Creek, which contains a spring of fair size, but flows mainly underground.

NIOBRARA RIVER.

This stream flows in a relatively shallow depression in the summit of the high table-lands lying between North Platte and White rivers. It enters Nebraska from Wyoming, and is a fine running stream of considerable volume throughout its course.

For this reason it was called by the Indians Niobrara, meaning "running water." This translation is still much in use, and the French equivalent, "L'eau qui court," is occasionally heard.

We have only two reports on the volume of the river, one of gaging made by Mr. E. T. Youngfelt June 23, 1896, at Marsland, where the flow was found to be 4 second-feet, which seems incredibly small, and the other, a measurement made by Prof. L. E. Hicks in range 51, Dawes County, of 98 second-feet on September 4, 1887.

The principal branch which this stream receives in western Nebraska is Whistle Creek, a flowing stream of small volume which heads in Coyote Springs. The other branches are very small and do not have flowing water at the surface.

WHITE RIVER.

The valley heading in Pine Ridge a short distance east of Harrison and opening diagonally out of the high lands near Crawford contains the headwaters of White River. From its head springs, near Andrews, it is a running stream which gradually increases in volume to the northeast and becomes a prominent river before leaving Nebraska. During the greater part of 1897 a gaging station was maintained at Crawford, Nebr., the results obtained being given on page 299 of Part IV of the Nineteenth Annual Report. The following gagings by Mr. E. T. Youngfelt indicate the volume of White River in early summer and the rate of flow of a number of its branches at various points:

Discharge measurements of White River and some of its branches. [a]

Stream.	Date.	Locality	Discharge per second.
			Cubic feet.
White River	June 24, 1896	Sec. 23, T. 31 N., R. 53 W.	23.30
Do	do	Crawford	30.70
Do	June 25, 1896	Whitney	27.20
Do	June 1, 1891	Chadron	123.00
Soldier Creek	June 24, 1896	Fort Robinson	3.23
White Clay Creek	do	N. line sec. 2, T. 31 N., R. 52 W.	4.00
Fort Robinson ditch	do	Fort Robinson	.79
Squaw Creek	do	N. line sec. 1, T. 31 N., R. 52 W.	.66
West Ash Creek	June 25, 1896	N. line sec. 25, T. 32 N., R. 51 W.	1.73
East Ash Creek	do	Half mile above mouth	1.09
Little Cottonwood Creek.	do	Sec. 7, T. 32 N., R. 51 W	.10
Big Cottonwood Creek.	do	6 miles west of Whitney	.20
Indian Creek	do	Near mouth	.06

[a] Eighteenth Ann. Rept. U. S. Geol. Survey (for 1896-97), pt. 4, 1897, p. 198.

White River receives numerous branches from the deep canyons in the north face of Pine Ridge between Glen station and Chadron, notably from White Clay, Ash, Indian, and Chadron creeks. Its principal affluent on the north side is Soldier Creek, which heads in T. 32, R. 54, and furnishes a considerable volume of water, in part used in irrigation at Fort Robinson. Little Cottonwood, Big Cottonwood, Lone Tree, and Rush creeks are the principal branches from the north and west. They furnish but small amounts of water and are usually in greater part dry during midsummer.

HAT CREEK BASIN.

Hat Creek and its numerous branches head in deep canyons along the north face of Pine Ridge from Round Top to the Wyoming line. A large amount of water is supplied by the head streams, notably Hat Creek and Sowbelly, Prairie Dog, Monroe, Warbonnet, and Jim creeks, but the amount diminishes rapidly by evaporation as the edge of South Dakota is approached. The branches which head among the low hills north of Pine Ridge contain water only in the rainy portion of the year.

IRRIGATION.

There is in this region considerable acreage under cultivation with the assistance of irrigation. There are extensive canals along the valley of North Platte River, several ditches along White and Niobrara rivers, and local arrangements for irrigation have been made in some of the smaller valleys. The results have been so satisfactory that there is prospect of some extension of irrigation operations. Much of the country is distant from good markets, and during the last few years farm products usually have not sold at profitable prices. The local demands, however, have often been sufficient to yield satisfactory returns to many of the irrigators. In Pls. XL and XLI are shown the canals and irrigated and irrigable areas in Nebraska west of the one hundred and third meridian and north of latitude 41° 30′.

NORTH PLATTE VALLEY.

The large volume of water in North Platte River and the wide bottom lands bordered by long zones of gentle slopes afford ideal conditions for irrigation in this valley. The soil is usually thick and rich and, although somewhat alkaline, responds most satisfactorily.

The history of irrigation in the valley dates back to the latter part of 1887, with the organization of the Farmers' Canal Company in Cheyenne County. Soon thereafter the Winter Creek, Minatare, and Enterprise canals were built, in 1888 and 1889, although the Enterprise canal was not entirely completed until somewhat later. The Minatare canal was begun in February, 1888, and opened August 20, 1888. These canals are all in Cheyenne and Scotts Bluff counties. The Mitchell canal was

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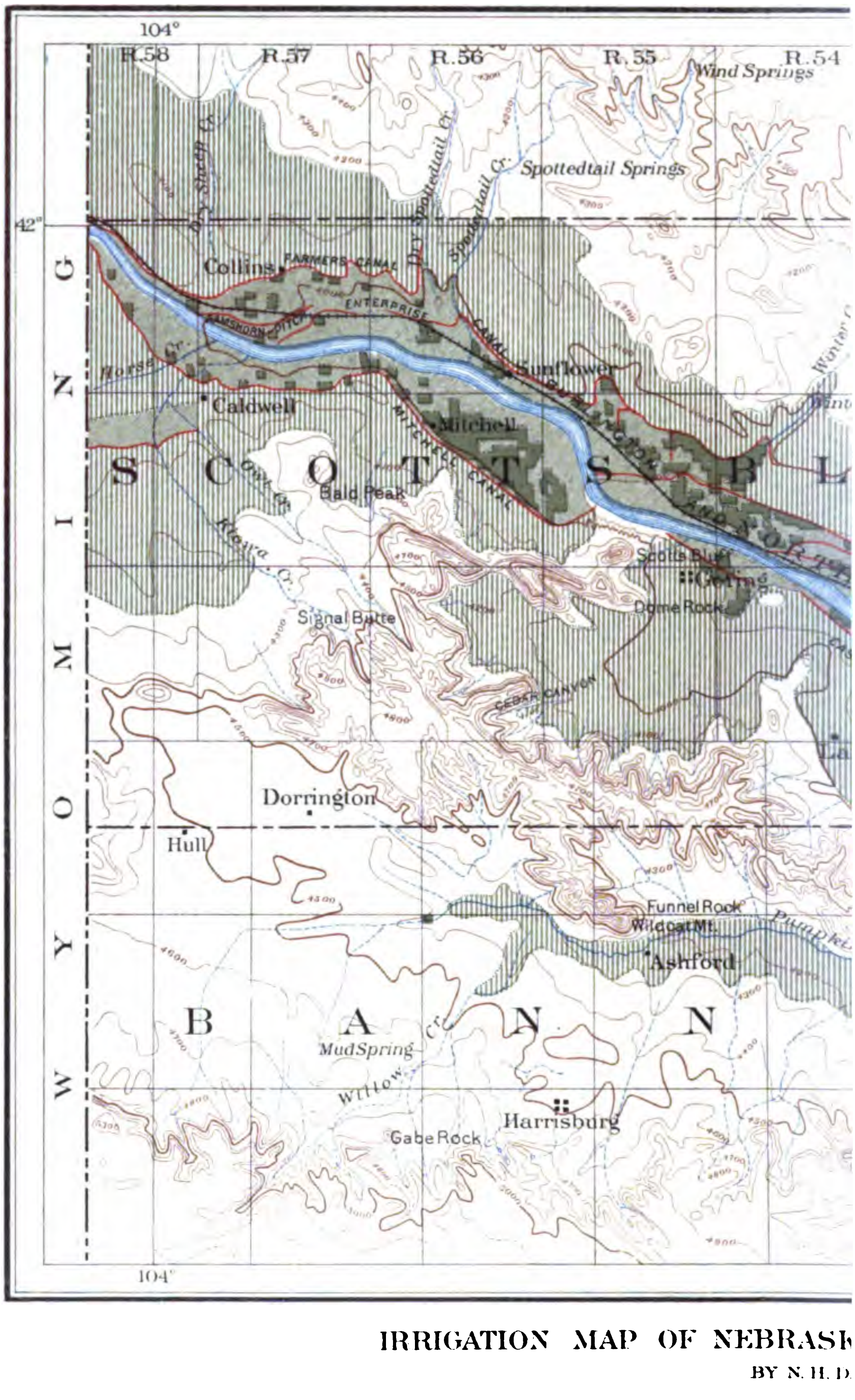
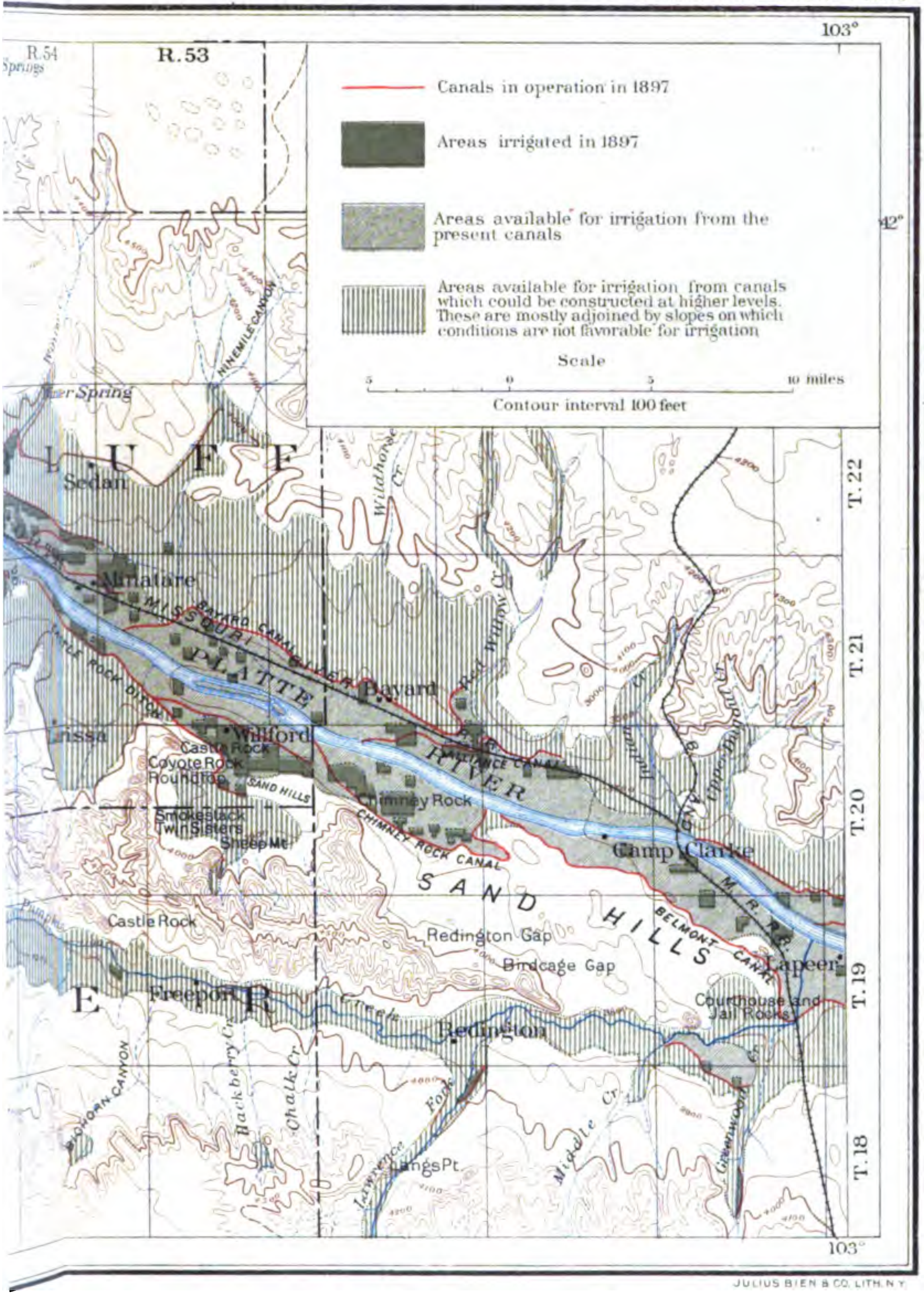


IRRIGATION MAP OF NEBRASK

BY N. H. D.



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BRASKA WEST OF THE 103D MERIDIAN

BY N H DARTON 1898

soon after constructed, in Scotts Bluff County, on the south side of the river west of Scotts Bluff. It is about 25 miles in length, 24 feet wide at the bottom, and conveys water to about 20,000 acres of bottom land. Early in 1888 the Castle Rock canal was constructed. It has a width of 18 feet on the bottom for the first 9 miles and then divides into two branches, each about 8 feet wide on the bottom and carrying 3 feet of water. Another large canal was built at Bayard. In 1893 the Ramshorn ditch was built in the western part of Scotts Bluff County. The Farmers canal has a head gate with a front opening 156 feet wide, with 27 individual gates. It is capable of taking an 8-foot head of water. The canal is 60 feet wide at the bottom and carries 8 feet of water. The first mile is completed 60 feet wide on the bottom, and for the remainder of its length its width is 30 feet. A gaging made at its head gate by Mr. E. T. Youngfelt on June 19, 1896, showed a flow of 2.28 cubic feet a second.

The following list comprises all the main canals, but not the many miles of laterals into which they empty:

List of irrigation canals in valley of North Platte River, in Nebraska, west of the one hundred and third meridian.

Name.	Location of intake.					Length.
Scotts Bluff County:						*Miles.*
Lawrence canal	Horse Creek	Wyoming				5
Mitchell canal	North Platte River	do				25
			Sec.	*T.*	*R.*	
Farmers canal	do		19	23	58	15
Ramshorn canal	do		34	23	58	6
Enterprise canal	do		12	23	57	22
Winter canal	do		35	22	56	11
Gering canal	do		7	21	55	5
Minatare canal	do		14	21	55	10
Castle Rock canal	do		19	21	54	15
Bayard canal	do		35	21	54	8
						122
Cheyenne County:						
Bayard canal	do		35	21	54	7
Chimney Rock canal	do		22	20	53	11
Alliance canal	do		23	20	53	10
Belmont canal	do		34	20	52	15
Browns Creek canal	do		11	19	51	6
						49
Total						171

The Lawrence canal derives its water from Horse Creek, in Wyoming, and it is supplemented by one 400-acre storage reservoir 10 feet deep and another covering 180 acres 11 feet deep.

The following estimates of crops raised in the Platte Valley are based on data obtained by Mr. C. A. Fisher and others during the autumn of 1897. In Scotts Bluff County the area irrigated from North Platte River in 1897 was 16,080 acres, in which wild hay, alfalfa, corn, and wheat were the principal crops. Oats and garden vegetables were also irrigated extensively. In Cheyenne County the area irrigated from North Platte River in 1897 was 4,150 acres, of which hay and alfalfa were the principal products, together with smaller amounts of various cereals and vegetables. The yield per acre of crops under irrigation is somewhat variable. Wheat usually harvests from 30 to 40 bushels an acre; potatoes, 150 to 200 bushels, and wild hay, 1½ tons. Alfalfa yields 2 tons to the cutting, and is cut three times a season. Near Sunflower post-office there is an extensive orchard under irrigation, which promises to be very successful. It contains about 3,200 trees, many berry bushes, and 5,000 strawberry plants.

The cost of irrigation was found to vary greatly. Figures were obtained for 7,500 acres in the Platte Valley, which indicate an average cost of 41 cents an acre. The farms are mostly from 80 to 160 acres. The individual cost an acre varied in greater part from 30 to 75 cents. In many cases the water was paid for partly in cash and partly in labor.

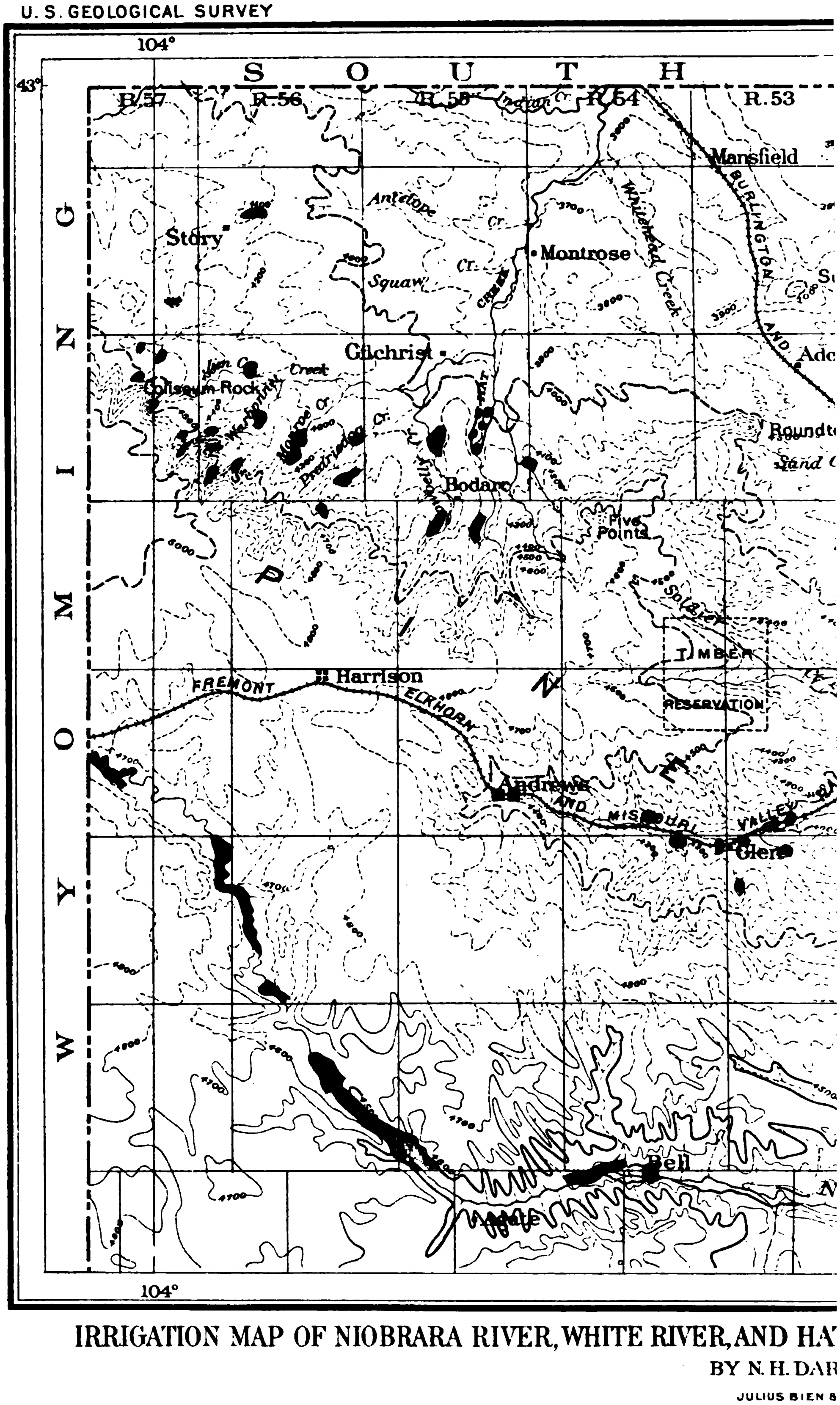
PUMPKINSEED VALLEY.

Pumpkinseed Creek is available for irrigation of a small marginal acreage along the greater part of its course, but the waters are used only to a small extent. There is a ditch, known as the Courthouse Rock canal, extending from the west line of range 50 to Greenwood Creek, a distance of 5 miles, and there are several small local ditches and reservoirs at various points, shown in Pl. XL. The area of crops is about 90 acres, embracing several hay meadows. Lawrence Fork is used locally for irrigation 2 miles south of Redington, and its excellent water supply would admit of much more extensive use.

NIOBRARA VALLEY.

The waters of Niobrara River are utilized extensively for the irrigation of narrow strips of the bottom lands. There are canals at frequent intervals along its course, which furnish water mainly for hay meadows. Some grain crops are raised, but their acreage is small. The total area under irrigation in 1897 was about 7,015 acres.

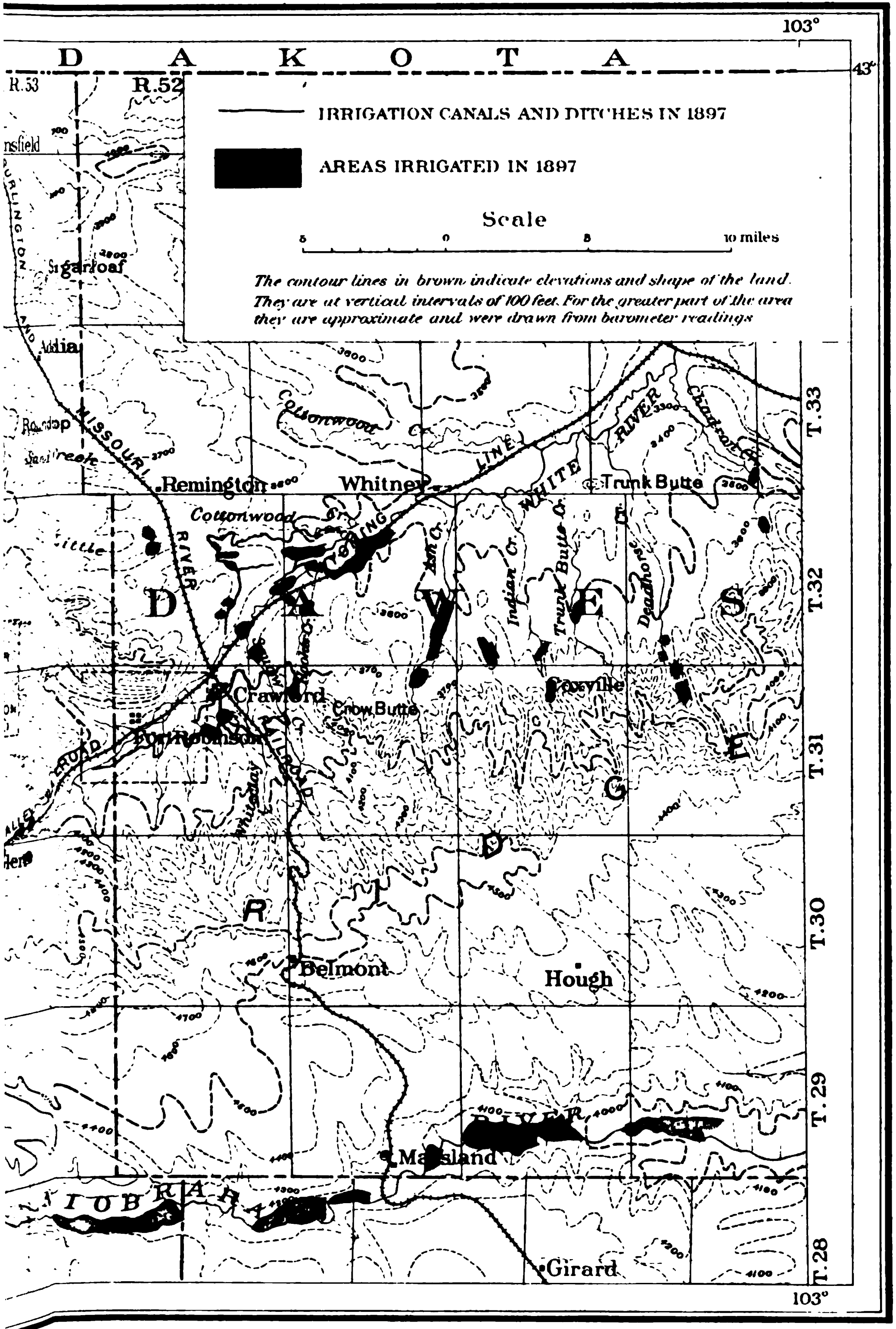
U. S. GEOLOGICAL SURVEY



IRRIGATION MAP OF NIOBRARA RIVER, WHITE RIVER, AND HA

BY N. H. DAR

JULIUS BIEN &



D HAT CREEK BASINS IN NEBRASKA WEST OF THE 103D MERIDIAN

H. DARTON 1898

LITH N.Y.

The following is a list of the canals, compiled from data recently obtained by the State engineer:

List of irrigation ditches along Niobrara River, in Nebraska, west of the one hundred and third meridian.

Name.	Location of intake.			Approximate length.
	Sec.	T.	R.	
Sioux County:				*Miles.*
Bigelow & Seymour ditch	19	31	57	1.75
Warneke's ditch	27	31	57	2.00
Johnson's ditch	36	31	57	.75
Lacota ditch	1	30	57	3.00
Peter Bourett's ditch	29	30	56	2.00
Earnest ditch	9	29	56	4.00
McGinley & Stover upper ditch	23	29	56	3.50
McGinley & Stover lower ditch	25	29	56	3.00
Harris & Neece ditch	3	28	55	10.00
La Belle ditch	6	28	54	2.00
——— ditch	4	28	54	4.00
Irion Brothers' ditch	1	28	54	2.00
Moore's ditch	9	28	53	3.50
Boxbutte County:				
McLaughlin ditch	9	28	52	3.00
Vincent ditch	10	28	52	1.00
Hughes ditch	1	28	52	2.00
Dawes County:				
Snow ditch	35	29	51	1.00
Palmer ditch	36	29	51	5.00
Furman ditch	29	29	50	3.00
Enterprise ditch	28	29	50	3.50
Hatch & Cross ditch	25	29	50	3.00
McMannis & Neeland ditch	29	29	49	2.00
Total	....	....	....	65.00

WHITE RIVER BASIN.

The relatively large volumes of running water in White River and those of its branches which head in the canyons on the north front of Pine Ridge have been utilized at various points for irrigation. Many ditches have been constructed, and there are plans for a more extensive use of the waters. At present about 3,655 acres are under irrigation, in greater part along the main valley.

The following list of ditches is compiled from data obtained by the State engineer during 1897:

List of irrigation ditches in White River Basin, in Nebraska, west of the one hundred and third meridian.

Name.	Location of intake.				Length.
Sioux County:		*Sec.*	*T.*	*R.*	*Miles.*
Lewis ditch	White River	27	31	55	0.50
Schwartz-Hughson ditch	do	26	31	55	.25
Tucker's ditch	do	34	31	54	.75
Colville ditch	Kyle Creek	3	30	54	1.00
Diedrichson ditch	White River	1	30	54	.50
Johnson ditch	do	7	30	53	.50
Jacobson ditch	do	32	31	53	.50
Mason ditch	do	32	31	53	.25
Crawford Citizens' ditch	do	23	31	53	1.50
					5.75
Dawes County:					
Crawford Citizens' ditch	do	23	31	53	18.50
Hazleton ditch	White Clay Creek.	13	31	52	1.00
Cooper ditch	do	2	31	52	1.75
Butterworth ditch	White River	3	31	52	.50
Hall's ditch	do	34	32	51	13.00
White River Irrigation Company's ditch.	do	34	32	52	2.00
McFarland's ditch	White Clay Creek.	35	32	52	.75
Harris & Cooper ditch	White River	25	32	52	10.00
Rasher ditch	do	19	32	51	1.00
Welling ditch	do	17	32	51	.50
Harris ditch	do	17	32	51	2.00
McManus ditch	Hooker Creek	7	31	51	1.00
Stewart Brothers' ditch	Little Cottonwood Creek.	8	32	52	1.50
Thomas Stewart ditch	do	8	32	52	.75
Spring Creek ditch	Spring Creek	13	32	52	.75
Spring Creek ditch No. 1	do	18	32	51	1.00
Kusil ditch	Little Cottonwood Creek.	9	32	51	1.00
Mace ditch	West Ash Creek.	2	31	51	1.00
West Ash Creek Irrigation Company's ditch.	do	36	32	51	2.00
Baron ditch	East Ash Creek.	32	32	50	.50
Ox Yoke ditch	do	31	32	50	1.50
James Wilson ditch	Indian Creek	10	31	50	.125
Seegrist ditch	do	3	31	50	.50

List of irrigation ditches in White River Basin, in Nebraska, etc.—Continued.

Name.	Location of intake.				Length.
		Sec.	*T.*	*R.*	*Miles.*
Dawes County—Continued.					
Flood ditch	East Fork of Indian Creek.	33	32	50	0.75
Smock's ditch	Trunk Butte Creek.	26	32	50	.50
Goff ditch	Dead Horse Creek.	9	31	49	1.00
Norton ditch	do	9	31	49	.75
Woodruff ditch	do	32	32	49	.75
Kemery Ram	do	32	32	49	.50
W. Wilson's ditch	Chadron Creek.	12	32	49	.50
H. M. Wilson's ditch	do	12	32	49	.75
Half Diamond	do	1	32	49	1.00
					69.125
Total					74.875

LODGEPOLE VALLEY.

The water of Lodgepole Creek has been utilized for irrigation for several years, and at times practically all the stream has been diverted into the fields. Hay has been the principal crop, but grains and vegetables have also been irrigated to some extent. The average volume of the creek is about 4 cubic feet per second, but along some portion of the valley the waters sink beneath the surface and, traveling underground for some distance, emerge again in springs. The following facts relating to this valley are taken from notes by Mr. Adna Dobson, made in the summer of 1895:[a]

Commencing from the west, the first ditch is the Hoover, which supplies water for about 50 acres; then come the ditches of S. A. Pierce and L. C. Kinney, which supply water for about 575 acres, mainly of hay lands. In the next 4 miles no more water is taken out, and then comes the head of the Young ditch, which supplies water for about 30 acres, extending to sec. 34, T. 15, R. 57. Five miles lower down is the ditch of Carl Ruttner, which takes water on each side of the creek, the total amount being 4.9 cubic feet a second, which is used for covering about 40 acres. One mile lower down is the beginning of J. J. Kinney's south ditch, which takes all the water in the creek, 3.6 cubic feet a second, for the cultivation of about 140 acres. One-half mile below this is the head of J. J. Kinney's north ditch, into which the entire creek is diverted. The amount of water is 2.1 cubic feet a second for the watering of 190 acres. These ditches are used alternately in order to obtain greater volume. The amount of water in the creek increases rapidly below the head of Mr. Kinney's ditch, and at the east line of sec. 34, one-half mile below, the creek is running about 6 cubic feet per second. Within the next 3 miles is the Hurley, Liley & Polly ditch, which takes 4.5 cubic feet of water a second for the irrigation of 160 acres. Two miles below this is the head of the Hurley & Polly ditch for the irrigation of about 125 acres. One-half mile lower down the valley is the head of the Bay State ditch, which takes 2.5 cubic feet of water a second for 100 acres. In the next 7 miles are the McIntosh, Circle Arrow, and Brady ditches, with only limited supplies of water, the creek becoming practically dry above Mr. Brady's head gate in sec. 28, T. 15, R. 54, and continuing so to a point in sec. 4, T. 14, R. 52, where it again appears. A measurement at the head of the Adams ditch, in sec. 31, T. 14, R. 52, showed 2¼ cubic feet a second, which is taken by the Adams ditch for the cultivation of 245 acres, mainly of hay. Next below is Thomas Gunderson's ditch, which has 5 cubic feet of water a second for 100 acres. In sec. 7, T. 14, R. 51, is the ditch of Mr. Hans Christianson, which takes about 1 cubic foot of water a second for 70 acres. One and one-half miles below this is the ditch of Mr. James Mitchell, which takes 3.5 cubic feet a second for 60 acres; and next below is the head of Mr. John Anderson's ditch, for 200 acres. This ditch is used alternately with the Mitchell ditch in order to have a sufficient volume of water. Then comes the very small ditch of Mr. J. A. Shanahan for the irrigation of 2 or 3 acres. The next dam below is for Mr. M. Urback's ditch. Then there is the ditch of N. P. Lingholm, which heads in the SE. ¼ sec. 14, T. 14, R. 51, and provides water for 30 acres. It was taking 1.5 cubic feet of water a second at the time of observation. The creek is dry below this through sec. 13 and nearly through sec. 19. Near the east line of sec. 19 the water rises again, and at the head of the Couch ditches, in the SW. ¼ sec. 20, T. 14, R. 50, 2 cubic feet a second is available for the irrigation of about 40 acres. Runge's ditches, Nos. 1 and 2, are in secs. 28 and 29, T. 14, R. 50, and provide for about 105 acres. The Ickes ditch comes next, but the amount of water is hardly sufficient to cover more than 100 acres. About one-half cubic foot of water a second passes the Ickes dam and fills a small pond at the head of the Adams & Tobin ditch, but the supply was inadequate to cover the 180 acres to be irrigated. Below this dam the creek is entirely dry for the next mile, where the water rises again in springs; and at the head of the Trognitz ditch, in sec. 36, T. 14, R. 50, one-half a cubic foot of water a second flows into the ditch and is used for the irrigation of about 34 acres. It is the same ditch that was built by the United States to supply water for Fort Sidney.

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[a] First Biennial Report of the State Board of Irrigation of the State of Nebraska for 1895 and 1896, prepared by W. R. Akers, Lincoln, 1897, pp. 151-157.

The table following gives the acreage of crops irrigated in the Lodgepole Valley west of the one hundred and third meridian in 1896, according to the first report of the State board of irrigation (p. 158).

Acreage of crops irrigated in the Lodgepole Valley west of the one hundred and third meridian in 1896.

	Acres.		Acres.
Alfalfa	317	Barley	20
Native hay	2,160	Rye	2
Corn	80	Potatoes	42
Oats	66	Garden trees, etc	25
Wheat	63	Total	2,832
Millet	57		

HAT CREEK BASIN.

The upper portions of Hat Creek and its numerous branches rising in canyons in the northern slopes of Pine Ridge contain water in sufficient supply for the irrigation of many local areas. These are mainly in the relatively narrow canyons, where only small strips of land are so situated as to be easily watered. The volume of water in most cases is ample and is derived from ever-flowing springs. Nearly all the canyons contain small, short canals, which serve for the irrigation of numerous small farms. The total area under irrigation in 1897 was estimated to be 1,860 acres.

The following is a list of the canals according to the plots of the State engineer:

List of irrigation ditches in Hat Creek Basin, Sioux County, Nebr.

Name.	Location of intake.				Length.
		Sec.	*T.*	*R.*	*Miles.*
Steel ditch	Hat Creek	16	32	55	1.50
Coffee's ditch	do	26	33	55	5.00
Miller ditch	do	23	33	55	.75
Holly's ditch	Boggy Creek	31	33	54	1.00
Old Sowbelly ditch	Sowbelly Creek	7	32	55	2.00
Hall's ditch	do	6	32	55	.50
M. D. Jordan's ditch	do	21	33	55	1.50
Schlitz ditch	Cedar Creek	35	33	56	2.00
Valdeg ditch	Prairie Dog Creek	3	32	56	.50
Zerbst ditch	do	25	33	56	1.00
Big Monroe Creek ditch	Big Monroe Creek	33	33	56	2.00
Biehle ditch		32	33	56	.75
Nolan's ditches, No. 1 and No. 2	Warbonnet Creek	23	33	57	1.25
Kay's ditch	do	26	33	57	.75
Daut ditch	do	30	33	56	1.00
——— ditch	do	31	33	56	1.00
Warbonnet ditch	do	21	33	56	1.50
Woodruff's ditch	Jim Creek	14	33	57	1.00
Slattery's ditch	do	13	33	57	1.00
Jim Creek ditch	do	8	33	56	.50
Hamlin ditch	Squaw Creek	10	33	57	.50
Dunn's ditch	do	11	33	57	2.00

List of irrigation ditches in Hat Creek Basin, Sioux County, Nebr.—Continued.

Name.	Location of intake.				Length.
		Sec.	*T.*	*R.*	*Miles.*
P. D. Dunn's ditch	do	3	33	57	1.00
Turner's ditch	Antelope Creek	26	34	57	1.50
Story's ditch	do	8	34	56	1.00
Cherry Creek ditch	Cherry Creek	29	33	54	.25
Total					32.75

WINDMILL IRRIGATION.

Several farmers in western Nebraska have experimented with windmill irrigation with encouraging results. There are large supplies of underground waters under the high table-lands, beginning with Pine Ridge and lying in broad expanse between the larger valleys. This is notably the case on the fine table lying between the valleys of Lodgepole Creek and Pumpkinseed Creek. These waters are usually at a depth of over 175 feet, but a large windmill soon raises sufficient water to fill a fair-sized reservoir. About 10 acres seems to be the limit for irrigation from one windmill, but this area will afford sufficient crops for local use. A reservoir is essential for satisfactory irrigation from a pump, but there usually is no difficulty in constructing one in the table-land areas.

CLIMATE.

Western Nebraska has a climate of typical plains character. It is dry and hot in summer, moderately moist in late spring, and cold, but with little snow, in winter. There is considerable variability in the climatic features from year to year, rather more than is found farther south or north, and some local variations from point to point, particularly in rainfall. Records of weather were kept for many years at Sidney, in the Lodgepole Valley, and at Fort Robinson, on White River, while for shorter periods observations have been made at Alliance, Gering, Hay Springs, Kimball, and Camp Sheridan. In Pl. XLII there is given a graphic reproduction of rainfall records covering a period of several years at some of the stations above mentioned, compiled from an article on the Rainfall of Nebraska,[a] by C. D. Swezey and G. A. Loveland, together with data for 1896 and 1897, kindly supplied by Mr. Loveland.

TIMBER.

The occurrence of timber in this region is restricted to certain localities of relatively limited extent. In the greater part of the plains area there is no timber at all, and the valleys of the Platte and upper Niobrara rivers and Lodgepole Creek do not contain trees. Along the northern escarpment of Pine Ridge, on the slopes of the White River and Hat Creek basins, there is a moderately wide zone of scattered

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[a] University of Nebraska, Bull. Agric. Exper. Stat., vol. 8, article 4, 1896.

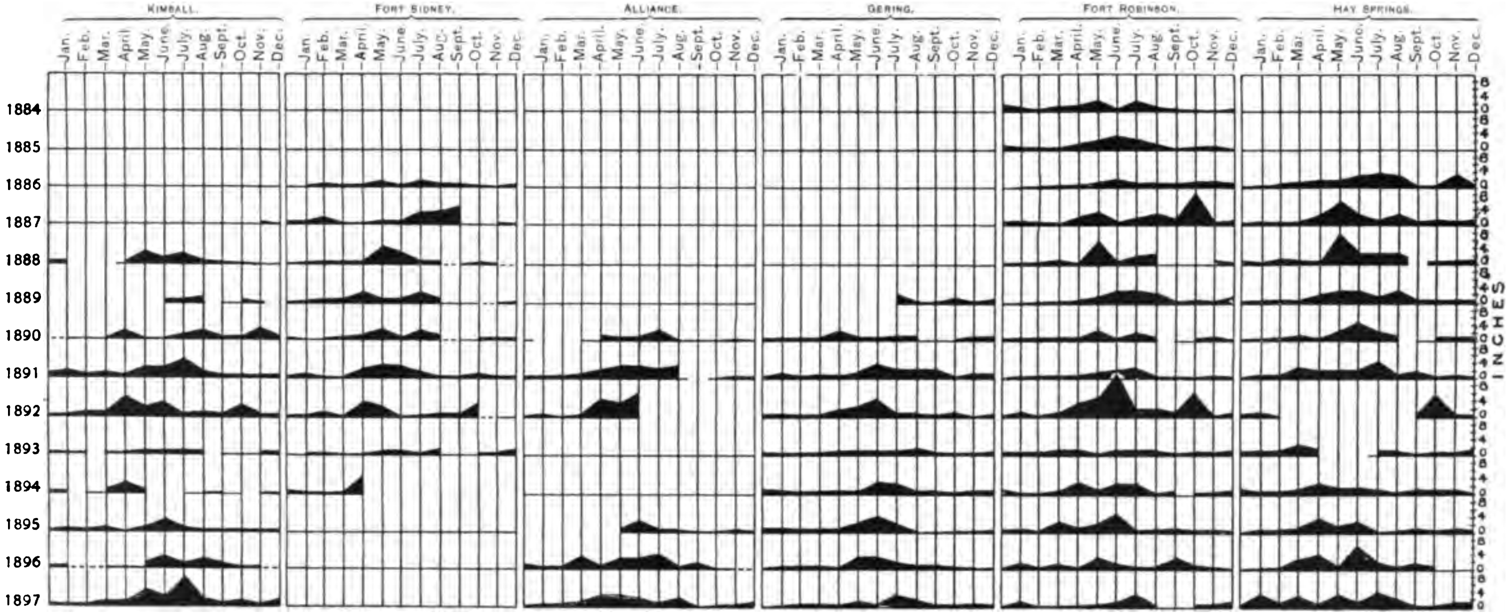

DIAGRAM OF RAINFALL AT LOCALITIES IN WESTERN NEBRASKA, 1884 TO 1897.

.... No precipitation. —— Trace. The absence of horizontal line indicates that no observations were recorded during a portion of the year.

pine forest. It extends from the crest of the ridge down nearly to the foot of the steeper slopes, and the aggregate amount of timber is fairly large. Along the ridge south of North Platte River there was formerly considerable pine, and many of the slopes north of Platte River and south of Pumpkinseed Valley maintained a scattered growth of pine. Some of the canyons in this region contain deciduous trees in small groves, and this is also the case in the many canyons in the northern slopes of Pine Ridge and at intervals along the banks of White River. The extent of the timber in this region is shown in Pl. XLIII. The principal tree is the Rocky Mountain pine (*Pinus ponderosa*). It attains a diameter of from 1 to 2 feet where the conditions are most favorable, but its growth is somewhat scattering, and deep inroads have been made on the supply by woodcutters. The young pines appear to be thrifty, as they spring up abundantly on most of the slopes, and are growing vigorously. Some features of the pine growth are shown in Pls. VIII and XXI.

In the region adjoining North Platte River the growth of pines is rather scanty, and nearly all of the larger trees have been or are being cut. This is also the case along the edge of the table-land south of Pumpkinseed Creek.

The deciduous trees of the region comprise mainly cottonwood (*Populus monilifera*), with a moderate proportion of box elder (*Negundium americanum*), and a small variety of other similar trees.

ELEVATIONS.

List of elevations in Nebraska west of the one hundred and third meridian.

WESTERN CHEYENNE COUNTY.

Locality.	Altitude.	Authority.
	Feet.	
Lapeer	3,638	U. S. G. S. bench mark.
Courthouse Rock	4,100	Do.
Jail Rock	4,002	Do.
Roundhouse Rock	4,255	Do.
Twin Mounds	4,309	Do.
Redington	3,870	Do.
Camp Clarke	3,705	Do.
Springs on Middle Creek	3,830	Do.
Chimney Rock	4,242	Do.
Bird Cage Gap	4,028	Do.
Bayard	3,780	Do.
Redington Gap	4,126	Do.
Cyrus	4,320	Do.
Spring Lakes	4,260	Do.
Duggers Springs	4,030	Do.
Ridge at head of McManigle Canyon	4,520	Do.
Table-land T. 22, R. 50 W	4,200-4,300	Do.

List of elevations in Nebraska west of the one hundred and third meridian—Continued.

WESTERN CHEYENNE COUNTY—Continued.

Locality.	Altitude.	Authority.
	Feet.	
Ickes post-office	4,415	Barometer.
Table at head of Wild Horse Canyon	4,450	U. S. G. S.
Sidney	4,090	Gannett.[a]
Margate siding	4,138	Union Pacific Railroad.
Bronson	4,203	Do.
Herdon siding	4,301	Do.
Potter	4,377	Gannett.[a]
Jacinto siding	4,486	Union Pacific Railroad.

KIMBALL COUNTY.

Locality.	Altitude.	Authority.
Dix	4,542	Union Pacific Railroad.
Owasco siding	4,616	Do.
Kimball	4,697	Do.
Adams	4,781	Do.
Bushnell siding	4,859	Do.
Smeed siding	4,925	Do.

BANNER COUNTY.

Locality.	Altitude.	Authority.
Wildcat Mountain	5,038	U. S. G. S.
Hogback Mountain	5,082	Do.
Castle Rock	4,472	Do.
Bighorn Mountain	4,718	Do.
Wrights Gap	4,425	Do.
Gabe Rock	5,006	Do.
Freeport	4,010	Do.
Harrisburg	4,500	Do.
Ashford	4,230	Do.
Mud Springs	4,640	Do.
Willow Springs	4,450	Do.
Funnel Rock	4,502	Do.
Gabe Springs	4,700	Do.
Long Springs	4,700	Do.
Summit of table south of Harrisburg	5,100	Barometer.
Smokestack Rock	4,326	U. S. G. S.
Sheep Mountain	4,507	Do.
Williams Gap	4,420	Do.
Hubbard Gap	4,494	Do.

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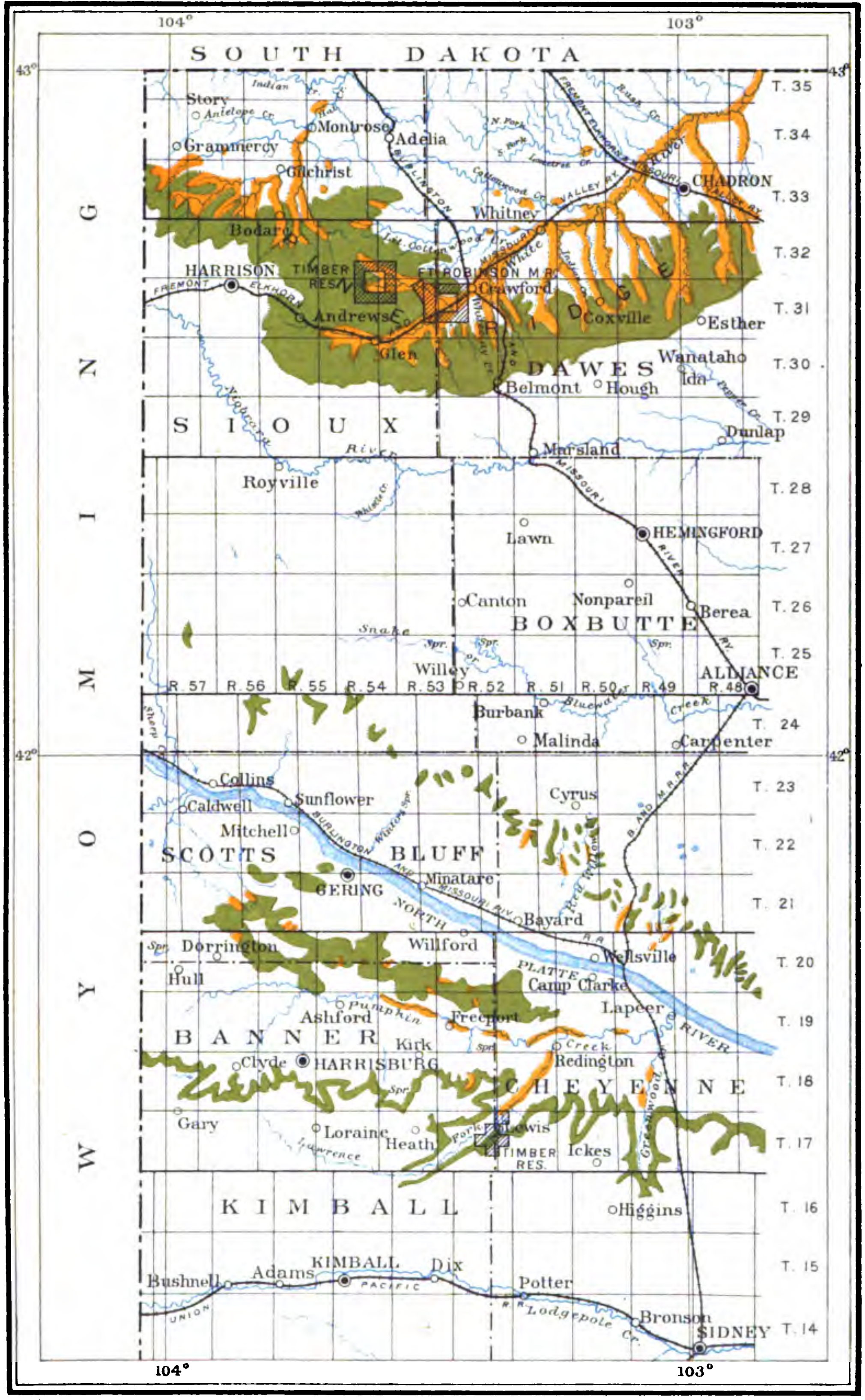
[a] Dictionary of altitude in the United States: Bull. U. S. Geol. Survey No. 160, 1899.



MAP SHOWING DISTRIBUTION OF TIMBER IN WESTERN NEBRASKA

BY N. H. DARTON

Scale of miles

10 5 0 10 20 30

■ PINE TIMBER ▨ COTTONWOOD, BOXELDER, AND OTHER DECIDUOUS TIMBER

JULIUS BIEN & CO LITH N.Y.

List of elevations in Nebraska west of the one hundred and third meridian—Continued.

SCOTTS BLUFF COUNTY.

Locality.	Altitude.	Authority.
	Feet.	
Scotts Bluff	4,662	U. S. G. S.
Dome Rock	4,560	Do.
Gering	3,902	Do.
Sedan	3,965	Do.
Winter Springs	3,990	Do.
Minatare	3,825	Do.
Sunflower	3,940	Do.
Collins	4,018	Do.
Caldwell	4,050	Do.
Mitchell	4,000	Do.
Larissa	3,960	Do.
Dorrington	4,450	Do.
Intake of Winter canal	3,900	Do.
Intake of Enterprise canal	3,980	Do.
Roubedeau Pass	4,480	Do.
Signal Butte	4,583	Do.
Summit of Ridge at head of Cedar Canyon.	4,860	Do.
Mitchell Pass	4,180	Do.
Bald Peak	4,420	Do.
North Platte River at Wyoming line	4,035	Do.
Castle Rock	4,473	Do.
Steamboat Rock	4,319	Do.
Roundtop Rock	4,479	Do.
Coyote Hill	4,460	Do.

SIOUX COUNTY.

Snyder's ranch	4,310	U. S. G. S.
Sturdivant's ranch	4,375	Do.
SW. corner of the county	4,050	Do.
NW. corner of the county	4,125	Barometer.
Harrison	4,849	F., E. and M. V. Rwy.
Andrews	4,422	Do.
Glen	4,038	Do.
Adelia	3,725	B. and M. R. R. R.
Mansfield	3,628	Do.
Niobrara River at Wyoming line	4,730	Barometer.
Niobrara River at eastern margin of the county.	4,200	Do.

List of elevations in Nebraska west of the one hundred and third meridian—Continued.

SIOUX COUNTY—Continued.

Locality.	Altitude.	Authority.
	Feet.	
Niobrara River at Royville	4,457	U. S. G. S.
Niobrara River at mouth of Whistle Creek.	4,280	Do.
Highest sandhill in sec. 17, T. 26, R. 55.	5,100	Do.
Highest sandhill in sec. 21, T. 27, R. 56.	5,020	Do.
Corbin's ranch	4,495	Do.
Mud Springs	4,470	Do.
Coyote Springs	4,520	Do.
McGinley Lakes	4,530	Do.
East Spring	4,525	Do.
Spottedtail Springs	4,120	Do.
Wind Springs	4,460	Do.
Gilchrist	3,900	Barometer.
Montrose	3,750	Do.
Roundtop	4,525	Do.
Coliseum Rock	5,050	Do.
Pine Ridge at Wyoming line, T. 33, R. 57.	5,060	Do.
Pine Ridge, south of Andrews	4,800	Do.
Pine Ridge, south of Glen	4,810	Do.

DAWES COUNTY.

Fort Robinson station	3,775	Gannett.[a]
Crawford	3,674	F., E. and M. V. Rwy.
Whitney	3,404	Do.
Dakota Junction	3,256	Do.
Remington	3,660	B. and M. R. R. R.
Rutland	4,141	Do.
Belmont	4,493	Do.
Marsland	4,156	Do.
Summit of Pine Ridge, near Belmont.	4,600	Barometer.
Niobrara River at 103d meridian	3,900	Do.

BOXBUTTE COUNTY.

Hemingford	4,256	B. and M. R. R. R.
Girard	4,365	Do.

[a] Loc. cit.

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Professional Paper No. 18

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

CHEMICAL COMPOSITION OF IGNEOUS ROCKS

EXPRESSED BY MEANS OF DIAGRAMS

WITH REFERENCE TO ROCK CLASSIFICATION ON A QUANTITATIVE CHEMICO-MINERALOGICAL BASIS

BY

JOSEPH PAXSON IDDINGS

WASHINGTON
GOVERNMENT PRINTING OFFICE
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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., May 26, 1903.

Sir: I have the honor to transmit herewith a manuscript by Joseph Paxson Iddings entitled "Chemical composition of igneous rocks expressed by means of diagrams, with reference to rock classification on a quantitative chemico-mineralogical basis," and to recommend that it be published as a Professional Paper.

The significance of a large number of chemical analyses of igneous rocks, with their many variable elements, each having a great range, is somewhat difficult of comprehension to all geologists and petrographers who have not devoted much time to their study. Mr. Iddings presents a method of expressing the most significant factors in each analysis by a simple diagram, and by grouping these individual diagrams on a certain principle he has succeeded in representing the great variation in composition and the chemical relationships of almost the entire range of igneous rocks in a way that is comprehensible at a glance. The facts thus brought out are discussed by him in their bearing on petrographic system. As a successful attempt at the elucidation of a complex problem the paper is of importance to all students of igneous rocks.

Very respectfully,

Whitman Cross,
Geologist in Charge, Section of Petrology.

Hon. Charles D. Walcott,
Director United States Geological Survey.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS EXPRESSED BY MEANS OF DIAGRAMS, WITH REFERENCE TO ROCK CLASSIFICATION ON A QUANTITATIVE CHEMICO-MINERALOGICAL BASIS.

By JOSEPH PAXSON IDDINGS.

INTRODUCTION.

The value of graphical methods for expressing relative quantities has been well established in all kinds of statistical exposition and discussion. Their use in conveying definite conceptions of relative quantities of chemical and mineral components of rocks is becoming more and more frequent, and the value of the results in some cases can not be overestimated. This is especially true when a series or group of rocks is being considered. The intricate variations in the amounts of numerous mineral components, or of chemical components, baffle most attempts to comprehend their interrelationships by simple contemplation or by study of the numbers in which they may be expressed. Many facts and relations are overlooked which are readily observed when diagrams are used to represent numerical figures. Moreover, visual memory is sufficiently developed in most persons to enable them to carry in mind simple geometrical forms, where it does not permit them to recollect manifold assemblages of oft-repeated numbers. Mental impressions of simple diagrams are, therefore, more definite and lasting and enable the student to store up a much greater amount of quantitative data than he could otherwise acquire.

Evidence of the appreciation of this fact by petrographers is found in the increasing use of diagrams in petrographical literature, and a brief sketch of the growth and elaboration of graphical methods for presenting quantitative petrographical data will serve as an appropriate introduction to the subject in hand. From this notice will be excluded those diagrams which serve to connect the names of rocks in series after the manner of expressing genealogical relationships, in which diagrams the space relationships are not strictly quantitative. Such diagrams have been used by George H. Williams, H. O. Lang, and other petrographers.

HISTORICAL REVIEW.

Among the earliest diagrams employed to represent relative quantities of rock constituents are those used by Reyer in 1877.[a] They are more or less generalized expressions, in one instance of the varying proportions of the chief oxide components in rocks and meteorites; in another of the varying amounts of the commoner rock-making minerals capable of being developed in rock magmas with different silica content. The diagrams used are rectangles subdivided by curved lines corresponding to the variations mentioned. Other diagrams express the variations of different kinds of rocks with respect to silica; the relation between specific gravity, silica percentage, and texture of mineralogically similar rocks; and the relative abundance of rocks of different compositions and textures.

Subsequently in his work, Theoretische Geologie,[b] he reproduces two of these diagrams and introduces others showing the proportions of chemical components in two series of minerals (feldspars and pyroxenes) and others showing the proportions of the chief minerals in three kinds of rocks. One diagram consists of adjacent, long, narrow rectangles, each divided into rectangular parts proportionate to the percentages of the oxide constituents in certain kinds of rocks, from granite to gabbro, and in five types of meteorites.

Judd,[c] in his book on Volcanoes, in 1881, makes use of a diagram to represent the varying amounts of chemical elements in rocks and meteorites. It is similar in form to one used by Reyer, already described.

In 1890 the author[d] constructed diagrams to exhibit the variation in chemical composition of rocks forming geologically related groups or series. In these diagrams the quantitative data represent specific analyses of different rocks in each series. The oxide constituents of each rock are referred to rectangular coordinates, the silica being plotted as abscissas, and the other oxides—alumina, ferric and ferrous iron, magnesia, lime, soda, and potash—being plotted as ordinates. Straight lines connecting successive loci of any one oxide, as those of alumina, indicate the variations in the amount of each constituent in the rock series. This is the chief feature brought out by these diagrams, the range and character of the variations being shown.

Similar diagrams have been used by Dakyns and Teall[e] to illustrate the chemical variations in the plutonic rocks of Garabal Hills and Meall Braec,

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[a] Reyer, E., Beitrag zur Fysik der Eruptionen. Vienna, 1877.

[b] Reyer, E., Theoretische Geologie. Stuttgart, 1888.

[c] Judd, J. W., Volcanoes. New York, 1881, p. 322, fig. 88.

[d] Iddings, J. P., The mineral composition and geological occurrence of certain igneous rocks in the Yellowstone National Park: Bull. Philos. Soc. Washington, vol. 11, January, 1890, pp. 207 and 211; also in Twelfth Ann. Rept. U. S. Geol. Survey, 1892, pp. 629 and 649; Mon. U. S. Geol. Survey, vol. 32, pt. 2, pp. 119 and 136; Origin of igneous rocks, Bull. Philos. Soc. Washington, vol. 12, June, 1892, and in Jour. Geol., vol. 1, 1893, p. 173.

[e] Dakyns, J. R., and Teall, J. J. H., Quart. Jour. Geol. Soc. London, vol. 48, 1892, p. 116.

Scotland; by Washington to express the chemical variation in the volcanic rocks of Ægina and Methana, Grecian Archipelago,[a] and in the rocks of Magnet Cove, Arkansas;[b] and by Cross[c] to show the chemical composition of the rocks of the Rosita Volcano, Colorado.

Harker[d] has employed the same form of diagram, but has used atomic ratios of the chemical elements instead of the oxides, to show the variations in the rocks of Carrock Fell, England. Subsequently he modified it slightly by using percentages of the oxide components instead of their molecular proportions to discuss the possibility of distinguishing igneous rock series from mixed igneous rocks.[e]

Loewinson-Lessing[f] has also made use of this method of exhibiting the variability of chemical composition in eruptive rocks, illustrating the great divergence in the composition of rocks classed under one name in the qualitative system and also the differences in composition of average magmas.

In 1900 Pirsson[g] pointed out the possibility of relating the variations in the chemical composition of rocks of one geological body to their position in that body by introducing their space relations into this form of diagram. He accomplished it by letting the abscissas represent distances in the rock body between the various rocks analyzed. By this modification of the diagram just described, he showed that the variations in chemical composition in such cases follow very regular laws, and with one or two elements determined in a variety of the rock the remainder may be found by means of the diagram.

Similar diagrams have since been used by Washington in discussing the differentiation in the rocks of Magnet Cove.[h]

Pirsson has also used a somewhat similar diagram to represent the variations in mineral composition of rocks of Yogo Peak, Little Belt Mountains, Montana.[i]

In 1896 Becke[j] represented the chemical composition of igneous rocks by diagrams of two kinds, constructed in a manner different from that of those just described. The first is a modification of a three-coordinate diagram for three variables, whose sum is a constant, based upon an equilateral triangle. The three factors chosen are Ca, Na, K. The zero point of the coordinate axis is the center of the triangle. From this point three axes run to the corners of the triangle, one for each of the elements, Ca, Na, K. The spot within the triangle determined by the values of Ca, Na, K, in a given rock analysis is the locus of the analysis (*Analysenort*). The various positions of these spots indicate the relative amounts of the elements named in the rocks compared. The other chemical elements in the rocks are represented on a second diagram supposed to stand at right angles to the plane of the first. It is drawn with rectangular coordinates, the abcissas being proportional to the ratio $\frac{Ca}{Ca + Na + K}$, and the ordinates representing the values of Si, Al, Fe, Mg. Each of these elements is located by a spot in the diagram.

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[a] Washington, H. S., Jour. Geol., vol. 3, 1895, p. 160.

[b] Washington, H. S., Bull. Geol. Soc. America, vol. 11, 1900, p. 404.

[c] Cross, W., Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 324.

[d] Harker, A., Quart. Jour. Geol. Soc. London, vol. 51, 1895, p. 146.

[e] Harker, A., Jour. Geol., vol. 8, 1900, pp. 389–399.

[f] Loewinson-Lessing, F., Compte rendu Congrès Géol. International, Seventh session, St. Petersbourg, 1899, Pls. I, II, and III.

[g] Pirsson, L. V., Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 569 et seq.

[h] Washington, H. S., Bull. Geol. Soc. America, vol. 11, 1900, p. 651.

[i] Op. cit., p. 568.

[j] Becke, F., Min. Pet. Mitth., vol. 16, 1897, p. 315–320.

In January, 1897, Michel Lévy[a] devised diagrams to exhibit certain chemico-mineralogical characters of igneous rocks, a single diagram representing an individual rock. The component oxides are first distributed into two groups, those that may combine with Al_2O_3 to form feldspars and those that may not. All the Al_2O_3 is set aside for feldspars, and to it is allotted K_2O, Na_2O, and sufficient CaO to satisfy it. An excess of CaO is placed with iron and magnesia. Silica may be introduced into the diagram or omitted, and in a subsequent publication[b] in the same year is expressed only in numbers stating the percentage. Rectangular coordinates are used and the values of the components are laid off on two axes intersecting at the zero point. Below this point is plotted the percentage of potash, and also that of iron oxide. To the right of the zero point is plotted the percentage of soda which may combine with alumina. In this direction, also, may be plotted the percentage of silica. Above the zero point is plotted the lime which may combine with alumina, and also the percentage of magnesia. If there is more lime than will satisfy the alumina remaining after potash and soda have been satisfied, this lime is plotted to the left of the zero point. Triangles are constructed by connecting the end of the potash line with that of the soda line, and the soda with feldspathic lime. Magnesia is connected with nonfeldspathic lime, and this with iron. Two triangles to the right of the y axis give an indication of the feldspathic constituents of the rock. The other two triangles to the left of the y axis represent the nonaluminous constituents. Modifications of the diagrams enter when there is an excess of alumina over alkalies and lime, and again when alumina is less than the alkalies.

Michel Lévy in the publication last cited also employs diagrams showing curves of variation for the percentages of the chemical components when subdivided in the manner just described.

These triangular diagrams have been used by Lacroix in describing the basic rocks accompanying the lherzolites and ophites of the Pyrenees,[c] and also in his work on the alkaline rocks of the petrographical province of Ampasindava, Madagascar.[a]

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[a] Lévy, A. Michel, Bull. Serv. Carte géol. France, vol. 9, No. 57, 1897, p. 38 and Pls. VII, VIII.

[b] Lévy, A. Michel, Bull. Soc. géol. France, 3d series, vol. 25, 1897, Pls. X to XV.

[c] Lacroix, A., Compte rendu Congrès Géol. International, Eighth session, Paris, 1901, Part II, pp. 834, 835.

In May, 1897, Brögger[b] presented a modification of the individual diagrams devised by Michel Lévy. This was done in illustrating the chemical composition of the group of rocks associated with the laurdalite of the Christiania region. Brögger's diagrams are composed of four coordinates in a plane intersecting in a common zero point. One is horizontal, another vertical, and the other two inclined, one 60° to the right, the other 60° to the left of the vertical axis. On these axes are plotted the molecular proportions of the chief oxide components of a rock. On the upper vertical axis are plotted the molecules of CaO, on the lower vertical axis the Al_2O_3. On the horizontal axis right and left is plotted the SiO_2, half and half. On the upper right inclined axis is plotted MgO; on the upper left one, the $FeO + Fe_2O_3$, indicated separately. On the lower right inclined axis is plotted K_2O, and on the lower left one Na_2O. The extremities of adjacent axes are connected by lines. These diagrams show at a glance the relative proportions of the molecules of the oxide constituents of each rock. The amount of CaO capable of being combined with Al_2O_3, not combined with K_2O and Na_2O, can be readily found by measuring the lengths of the several axes. The introduction of the silica and alumina adds to the instructiveness of this form of diagram.

Diagrams of this type have been employed by Hobbs[c] to express the average composition of groups of rocks classed together under various divisions of the qualitative system in general use at the present time. In these diagrams the inclined axes stand at 45° to the vertical axis.

Hackman[d] has made use of both the Becke and the Brögger diagrams to express chemical relations among the rocks associated with ijolite in Kuusamo, Finland.

Rosenbusch[e] uses narrow rectangular diagrams to express the relative proportions of the chemical elements (*Metallatome*) in two series of 26 rocks; one, a foyaite-theralite series, the other a granitodiorite and gabbro-peridotite series.

In February, 1898, the author[f] in an essay on rock classification, and later in another essay, made use of diagrams exhibiting the variations of rock analyses with reference to percentage of silica and alkali-silica ratio. These are constructed by using the silica percentages as abscissas, the zero point being to the right of the diagram, and 100 to the left. The ordinates represent the ratios obtained by dividing the sum of the molecular proportions of the alkalies, K_2O and Na_2O, by that of silica. The locus of each analysis is indicated by a round spot or by figures of other shapes.

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[a] Lacroix, A., Nouv. Arch. Museum Hist. Nat., 4th series, I, Paris, 1902, p. 180 et seq.

[b] Brögger, W. C., Die Eruptivgesteine des Kristianiagebietes. III. Videnskabsselskabets Schrifter. I. Math.-Naturv. Kl. 1897. No. 6. Christiania, 1898.

[c] Hobbs, W. H., Jour. Geol., vol. 8, 1900, pp. 1-31.

[d] Hackman, V., Bull. Com. Geol. Finlande, vol. 11, Helsingfors, 1900.

[e] Rosenbusch, H., Elemente der Gesteinslehre. Stuttgart, 1898.

[f] Iddings, J. P., Jour. Geol., vol. 6, 1898, pp. 92-111, 219-237.

In the same year, 1898, Michel Lévy[a] presented a new mode of coordination of diagrams to represent rock magmas, based in a measure on those just published by the author, to some features of which Michel Lévy took exception. These diagrams by Michel Lévy give the loci of rock analyses referred to two coordinates in the plane of drawing, and also to a third axis projected on the same plane. The abscissas (x) represent the silica percentages in the "white components" (elements blancs) of the rocks compared. The ordinates (y) represent the sum of the percentages of K_2O, Na_2O, and the CaO which may enter feldspar combined with Al_2O_3. The third coordinates (z) represent the percentages of MgO, FeO, Fe_2O_3, CaO, and SiO_2 in the ferromagnesian components of the rocks. The loci of the analyses are fixed by the rectangular coordinates x and y. Their relation to the axis z is indicated by their position with reference to diagonal lines representing the projected traces of certain planes with an inclined plane through z.

The usefulness of this diagram, which appears when the compositions of restricted groups of rocks are illustrated, is seriously impaired by repeated overlapping when many kinds of rocks are taken into account. The method undertakes to distribute the analyses with respect to the relative abundance of the white (leucocratic) components—quartz and feldspathic minerals—and the dark (melanocratic) ferromagnesian components in the first instance, and also with respect to the silica content of the leucocratic components.

It is clear that rocks containing various amounts of nephelite, leucite, and anorthite molecules with closely similar percentages of silica will be mingled together in the same part of the diagram, and that rocks with preponderant ferromagnesian minerals, since they are plotted wholly on a basis of characters belonging to the subordinate feldspathic minerals, will be indiscriminately mingled in one portion of the diagram.

In 1899 Loewinson-Lessing,[b] in his studies of eruptive rocks, an abstract of which was presented, without diagrams, to the International Geological Congress at St. Petersburg in 1897, makes use of two forms of diagrams, one after the method of the author, already alluded to, and another based on the method of relative rectangular areas used by Reyer. The diagram represents the various molecular proportions of the chemical components of a rock, or may represent the average of a group of rocks. It is a rectangular area divided by horizontal lines into spaces whose vertical dimensions correspond to the proportions of SiO, R_2O_3, RO, and R_2O in each case. These rectangles are subdivided by vertical lines into spaces whose horizontal dimensions correspond to the proportions of Al_2O_3 and Fe_2O_3 in R_2O_3, of FeO, CaO, and MgO in RO, and of K_2O and Na_2O in R_2O.

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[a] Lévy, A. Michel, Bull. Soc. géol. France, 3d series, vol. 26, 1898, Pls. III to VI.

[b] Loc. cit.

In 1900 Mügge[a] devised a form of diagram to express the proportions of the chemical components of rocks, based upon some features of Michel Lévy's and Brögger's diagrams. Several modifications of the diagram were suggested by Mügge. It will be sufficient to describe the form used by him to illustrate the composition of a number of selected rocks. The relative quantities of the oxide components, expressed molecularly, are plotted on four coordinate axes in one plane intersecting in a zero point and making equal angles with one another. One is vertical, one horizontal, and two inclined at 45°. The silica is represented by an octagonal area, constructed by plotting one-eighth of the total silica plus and minus on each axis. The other components are plotted outside this area on particular axes by adding their values to the silica already plotted. K_2O is plotted on the upper left inclined axis, Na_2O on the upper right one, MgO on the lower left inclined axis, CaO on the lower right one. FeO is plotted on the lower vertical axis, followed by Fe_2O_3 in the same direction. Al_2O_3 is divided into three parts, when sufficient, the first, equal molecularly to K_2O, is plotted to the left on the horizontal axis. A second, equal to the Na_2O is plotted upward on the vertical axis, and the remainder of the Al_2O_3 is plotted to the right on the horizontal axis. When there is less Al_2O_3 than $K_2O + Na_2O$, enough Fe_2O_3 is added to Al_2O_3 upward on the vertical axis to equal Na_2O. In this manner the relative amounts of potash-alumina molecules, soda-alumina molecules, and lime-alumina molecules are indicated.

In 1900 and 1901 Osann[b] made use of several types of diagrams to illustrate chemical characteristics of igneous rocks in his essay on a chemical classification of igneous rocks.

One is a triangular diagram somewhat similar to that used by Becke, exhibiting the distribution of analyses with respect to three coordinate axes making equal angles with one another. The three chemical factors of rocks employed in their comparison are chemico-mineralogical to some extent. One factor (A) consists of the sum of the percentages of K_2O and Na_2O which may be combined with Al_2O_3 in equal molecular amount. A second factor (C) represents the percentage of CaO which may be combined with Al_2O_3 in equal molecular amount. The third factor (F) represents the sum of the percentages of the remaining CaO,

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[a] Mügge, O., Neues Jahrb. Min., Geol. und Pal., 1900, vol. 1, pp. 100-112, Pls. V-VII.
[b] Osann, A., Min. Pet. Mitth., vol. 19, 1900, Pls. IV-VIII, XXV; vol. 20, 1901, Pls. VIII-XIV.

MgO, FeO. The sum of these is assumed to be a constant, and their relative proportions are determined on a basis of 20 units. With these three variables the position of a rock analysis within the equilateral triangle is located.

A second form of diagram expresses the variation in silica and alkalinity in certain rocks by means of lines connecting loci of analyses referred to two rectangular coordinates, the abscissas corresponding to the alkalinity, and the ordinates to the silica percentage. Another diagram of the same type exhibits the variability of different kinds of rock with respect to the relative proportions of soda and potash.

A third form of diagram is composed of narrow rectangles, whose lengths correspond to the range of variation in silica ratios for different kinds of rocks. The rectangles are placed by the side of one another, with their longer diameters adjusted to one ordinate representing values of silica ratios.

In 1902 Reid[a] used an equilateral triangle whose sides are divided into 100 parts, as a basis on which to plot the oxide components of igneous rocks.

PURPOSE OF THE DIAGRAMS.

A study of the various diagrams that have been employed by petrographers shows that their value depends upon the readiness with which their significance may be grasped and the use that is made of them. The first condition varies directly as the simplicity of the method of construction, both as to geometrical form and as to the factors on which they are based. The simpler the form of the diagram and the more characteristic its shape, the more definite the visual impression and the stronger the hold on the mind. It is also self-evident that the simpler the factors entering into it the better. The quantitative values of single rock components are simpler conceptions than intricate ratios and functions involving several different rock components. Moreover, a diagram is comparatively worthless unless it can be made to convey some definite impression not otherwise obtainable, or obtainable only with difficulty. Its employment should have some specific object. It is hoped that the diagrams presented in this paper will justify themselves and will produce certain definite impressions on the minds of petrographers who may study them.

The author's first purpose in constructing the accompanying diagrams is to express in the simplest graphical manner the chief chemical composition of all kinds of igneous rocks in a form that will permit the student to compare them at a glance and obtain a comprehensive view of the whole range of differences.

The diagrams are intended to exhibit the manifold character of the variations of the chemical components of rocks, and their extent. They are to show the gradual character of the variations; the transitions from rocks of one composition to those of another; and the distribution of the rocks throughout the range of their variations.

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[a] Reid, J. A., Bull. Dept. Geol. Univ. California, vol. 3, 1902, p. 18.

They are to demonstrate the absence of clusters of analyses in definite parts of the whole system and the absence of "natural" subdivisions of rocks on a basis of chemical composition.

They are to show the possibility of continuous series of rocks with diverse compositions, and to illustrate the chemical identity of rocks belonging to different genetic families.

Finally the diagrams exhibit the character of the quantitative classification of igneous rocks proposed by Cross, Iddings, Pirsson, and Washington, the range of composition of the five classes, as well as of the orders, rangs, and subrangs.

CONSTRUCTION OF THE DIAGRAMS.

As will be seen by looking at the plates, the diagrams are combinations of two kinds already in use. They consist of assemblages of individual rock diagrams, which are modifications of those devised by Michel Lévy and Brögger, the individual diagrams being arranged in a multiple diagram previously used by the author. The first are used to exhibit the chief chemical components of each rock taken into consideration; the second, to arrange these in an orderly manner for comparison with one another.

The small, individual diagrams are modified forms of those by Brögger. They are planned to exhibit the relative amounts of the chief oxide components of igneous rocks, namely: SiO_2, Al_2O_3, Fe_2O_3+FeO, MgO, CaO, Na_2O, K_2O, and also TiO_2. Other components are usually so slight that they are negligible in diagrams of such small scale. Owing to the fact that the small diagrams are arranged in the large diagram according to the silica, it is not necessary for the purposes of this paper to introduce SiO_2 into the construction of the individual diagram. The relative amount of SiO_2 is expressed by the position of the small diagram in the large one. This simplifies the small diagram.

The chemical components of rocks may be compared with one another as oxides of metals or as metals. As oxides, the form in which they are expressed in chemical analyses of rocks, they may be compared by means of percentage weights or of molecular proportions. As metals they would be compared by molecular or atomic proportions.

The use of oxides instead of metal elements is the more convenient method of comparison. It bears a more obvious and direct relation to the rock analysis and requires less effort to apply. It is as valuable in the discussion of chemico-mineralogical relationships as the use of metal elements. It has, therefore, been adopted in constructing these diagrams.

The value of basing the comparisons upon molecular proportions instead of percentage weights rests upon the fact that the chemical equivalency of the components is molecular or atomic, and that in this form they may be readily converted into mineral molecules for purposes of discussion and rock classification.

For purposes of comparison in diagrams of this type it is not necessary to reduce the original analysis to a sum of exactly 100. So far as the small individual diagrams are concerned the amount of change produced in the lengths of the lines would not be appreciable. Further, all elementary lines in one diagram would be affected in like proportion and the shape of the figure would remain unchanged, even could the alteration in the length of the lines be made visible. It would affect to a variable degree the position of the small diagrams within the large one in the direction of the silica abscissa, which will be discussed later.

The small, individual diagrams are constructed to exhibit the molecular proportions of the component oxides: Al_2O_3, Fe_2O_3+FeO, MgO, CaO, Na_2O, K_2O, and TiO_2. These are derived directly from the rock analysis by dividing the percentage weight of each oxide by its molecular weight. There is no further reduction. They are used in the proportions in which they are found in the rock, the assumption being that equal weights of different rocks are being compared.

Following Brögger's method, the several values of these oxides are plotted on coordinate axes in one place, intersecting at a common zero point. But the arrangement is different. For convenience in drawing on square-ruled paper the axes chosen are vertical, horizontal, and two at 45° to these. The simple, approximate relation between the sides and hypothenuse of a 45° triangle, namely, that when the hypothenuse is 10 units the sides are 7 units each (more exactly 7.071) allows the values to be readily plotted by assuming the diagonal of each square of the ruled paper to be 5 and the side 3½. With larger diagrams and more exact requirements more accurate methods of plotting may be employed.

Since the small diagrams are to be compared by means of the multiple one, the position of the Brögger diagrams is inverted to conform more closely to the manner of constructing the large diagram. In the multiple diagram the more alkalic, and consequently more alkali-feldspathic, members of the series of rocks compared occur in the upper part; the less alkalic, and more ferromagnesian, in the lower part. So the alumina and alkalies are placed in the upper part of the individual diagrams, the iron and magnesia in the lower. The mode of construction is as follows: Al_2O_3 is plotted upward on the vertical axis; K_2O upward to the left on one inclined axis; Na_2O upward to the right on the other inclined axis; CaO is plotted downward on the vertical axis; MgO downward to the right; $FeO+2Fe_2O_3$ downward to the left; and TiO_2, when present in appreciable amount, is plotted to the left on the horizontal axis. The end of the Al_2O_3 ordinate is connected by lines with the ends of the K_2O and Na_2O ordinates, producing two triangles having a common side—the Al_2O_3 ordinate—and one angle the same in each—45°. Consequently the areas of the two triangles are proportional to the lengths of the K_2O and Na_2O ordinates. The relative impressions produced by these two triangles, colored green and yellow in the diagrams, are quantitatively the same as the relations between the molecular proportions of K_2O and Na_2O in the rock.

The end of the CaO ordinate is connected with the ends of the MgO and $FeO+2Fe_2O_3$ ordinate, making two triangles, colored blue and red in the diagrams, whose areas bear the same proportion to one another as the ratio between the molecules of MgO and the iron converted to FeO.

When TiO_2 is represented, the end of its ordinate is connected with that of the FeO ordinate.

The FeO and Fe_2O_3 are combined chiefly for simplicity, and the Fe_2O_3 is reduced to FeO because there is then a more uniform basis of comparison and a means of avoiding the analytical defects or errors in the determination of the two oxides of iron. The combination prevents a proper conception of the possibilities of mineral molecular combination so far as the iron is concerned, but this is beyond the adaptability of the diagrams in a strict sense.

It is evident that diagrams constructed on the molecular proportions of the oxide components of rocks may be easily converted into others, based on the proportions of the metal elements, by doubling the lengths of the three upper ordinates, Al_2O_3, K_2O, Na_2O. The upper half of each diagram would be double its former size, while the angular shape of the whole would remain the same.

The multiple diagram, by which the small individual ones are arranged for comparison and study, is constructed in the manner already described in the article on rock classification previously cited. It is intended to exhibit the distribution or variation of igneous rock analyses with respect to the silica and alkalies. The reasons for choosing these two factors are: First, the important rôle played by silica, the most abundant chemical component, and that which is dominant in the development of quartz, orthoclase, albite, leucite, or nephelite, orthorhombic pyroxene or olivine; second, the equally important rôle played by the alkalies in conditioning the character of the feldspathic mineral components of rocks, which are the preponderant ones in the great majority of cases; third, the fact that the other chemical components—lime, magnesia, and iron oxide—sustain to a considerable extent a reciprocal relation to those just mentioned. The greater the silica the less the content in lime, magnesia, and iron oxide. The same is true in general for the alkalies and these oxides.

One of the chief purposes of the diagram is to distribute the rocks in an orderly manner, so that unlike rocks shall be separated from one another as widely as possible and gradations between the extremes shall be made evident.

The silica is made the abscissa because it is the greater component and has the widest range. It is plotted in percentages instead of molecular proportions because the process is simpler, and as it is not brought into immediate quantitative relations to the linear elements of the individual diagrams there is no occasion for its quantitative linear comparison with them. Moreover, the large diagram could not be constructed on the same scale of units as the individual diagrams. It is therefore simpler and more convenient to use the percentage of silica given in the analyses.

The vertical ordinates represent the ratio between the sum of the molecular proportions of the alkalies ($K_2O + Na_2O$) and of the silica — $\frac{(K_2O + Na_2O)}{SiO_2}$. This ratio was selected because of the relation between the development of the alkali-feldspathic minerals in highly feldspathic rocks and the ratio between the alkalies and silica in their magmas; the more siliceous ones yielding more orthoclase or albite, the less siliceous ones more leucite or nephelite. It is not a definite relationship in rocks generally, and, as Michel Lévy has pointed out, the character of the diagram would not have been altered materially had the vertical ordinates been made to correspond directly to the sum of the alkalies. In this case the curved lines which represent the loci of pure quartz-albite-nephelite rocks and quartz-orthoclase-leucite rocks would be straight lines instead of hyperbolas, as in the diagrams here used. There would be a slightly different vertical spacing of the analyses on individual diagrams. They would be spread more on the left side of the ordinate of 60 per cent SiO_2, and condensed more on the right of it. The multiple diagrams would be more simply constructed. Otherwise the results would be alike.

With diagrams constructed by using ratios between two or more rock components it matters not whether the analyses discussed by it are reduced to anhydrous compounds, or whether their summation is exactly 100. The ratio between the alkalies and silica is not affected by readjusting the analysis. The ordinate of an analysis so located is not changed by readjusting the percentages in the analysis, but the abscissa would be affected by changing the silica percentage. The position of an analysis would be shifted horizontally to the left or right according as the percentage of silica is raised or lowered.

The zero point of each individual diagram is located in the multiple diagram by reference to the silica percentage and the alkali-silica ratio of the analysis it represents. In some instances several individual diagrams belong so close together that they would overlap, so as to prevent their shapes from being easily seen. One or more of them is moved to the nearest available space in the multiple diagram. From this it happens that the distribution of the analyses in the large diagram is not strictly correct in the more crowded portions of it. A more exact representation of the distribution is given in another form of multiple diagrams on a smaller scale, in which round spots take the place of the individual diagrams.

ROCK ANALYSES USED IN CONSTRUCTING DIAGRAMS.

Having described the methods by which the diagrams are constructed, a more important matter to be considered is the data to be used—the rock analyses to be compared by them.

Analyses have been selected from all sources available, but not all analyses. It is important that they be correctly made and from good material. These conditions, however, can not always be recognized or known without careful study of the publications in which the analyses appear, and not always then. The collection is not above criticism in this respect. However, care was exercised to omit obviously defective analyses, as well as those from plainly declared altered rocks, except in cases where the altered form may be assumed to correspond approximately to the fresh rock, with the addition of water of hydration. For the strongly ferromagnesian rocks such analyses have been taken sometimes in default of better.

The analyses represent as many varieties of igneous rocks as could be found, with as wide a range as possible. Many analyses closely similar to those introduced into the large diagrams have been omitted because there was not space for them. Consequently the diagrams do not show the proper proportions between the commoner and rarer varieties of rocks. This can be shown by plotting the loci of all acceptable analyses by means of spots in a multiple diagram of fairly large scale. This has been done in constructing the diagram on Pl. VIII, which is composed of 2,000 analyses.

It was thought unnecessary to reprint the analyses themselves, for the reason that nearly all of them will be found in the collection of rock analyses made by Dr. Henry S. Washington and published by the United States Geological Survey,[a] and a large part of them also in Bulletin of the United States Geological Survey No. 168. Many of them will be found in Rosenbusch's Elemente der Gesteinslehre. So that these collections should be used in connection with the diagrams. For this reason reference is given in many cases to these publications, and to others where numerous analyses are assembled, instead of to the original sources, as the more convenient method of finding them.

A list of the analyses used in the diagrams is given. Their positions on the diagrams may be found by means of the silica percentage and alkali-silica ratio, which are stated in each case, besides the position given them when placed differently.

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[a] Chemical analyses of igneous rocks from 1884 to 1900: Prof. Paper U. S. Geol. Survey No. 14.

They are classified according to the quantitative classification, and the author wishes to express his thanks to Dr. Washington for the labor he has bestowed on the comparison of the list with his collection and for the correction of errors that appeared in the list. He is indebted to him also for valuable additions to it.

The list is far from complete, and petrographers may add to it and to the diagrams data which should have been included. But it seems as though enough has been introduced to accomplish the purpose for which the diagrams were prepared.

In order to shorten the references in the lists, a number of abbreviations are used which are given alphabetically.

ABBREVIATIONS EMPLOYED IN BIBLIOGRAPHIC REFERENCES.

A. G	American Geologist. Minneapolis.
A. J. S	American Journal of Science. New Haven.
A. W. B	Sitzungsberichte der König. Preuss. Akad. der Wissensch. Berlin.
A. W. W	Sitzungsberichte der K. Akad. Wissensch. Wien.
B. C. G. F	Bulletin de la Commission géologique de Finlande. Helsingfors.
B. G. S. A	Bulletin of the Geological Society of America. Rochester.
B. M. A	Bergens Museums Aarbog.
Bull. 168	Bulletin of the U. S. Geological Survey, No. 168. Washington, 1900.
C. G. I	Congrès géologique International, Compte Rendu, VIII session. Paris.
E. K	Die Eruptivgesteine des Kristianiagebietes, W. C. Brögger. Christiania. I, 1894; II, 1895; III, 1898.
G. C	Untersuchung einiger Gesteinssuiten gesammelt in Celebes, von P. and F. Sarasin. C. Schmidt, Wiesbaden, 1901.
G. F. S. F	Geol. Fören. i Stockholm Förhandl.
I. R. A	The igneous rocks of Arkansas: vol. 2 of Ann. Rept. Geol. Surv. Arkansas.
J. G	The Journal of Geology. Chicago.
O. N	Recherches géologiques et pétrographiques sur l'Oural du Nord, Duparc et Pearce. Part I. Geneva, 1902.
M. M	Materiaux pour la Minéralogie de Madagascar, A. Lacroix. Nouvelles Archives du Muséum. 4th series, Vol. I. Paris, 1902.
N. J	Neues Jahrbuch für Mineralogie, Geologie, etc.
Q. J. G. S	Quarterly Journal of the Geological Society of London.
Rosenbusch, El	Rosenbusch. Elemente der Gesteinslehre. Stuttgart, 1898.
R. T	Roth's tables of rock analyses. Beiträge zur Petrographie der Plutonischen Gesteine. Berlin.
S. M. Q	School of Mines Quarterly. New York.
T. M. P. M	Tschermak's Min. u. Petr. Mitth. Vienna.
W. T	Washington's tables of chemical analyses of igneous rocks from 1884 to 1900. Professional Paper U. S. Geological Survey, No. 14, Washington, 1903.
Z. D. g. G	Zeitschrift d. Deutschen geol. Gesellschaft. Berlin.
Z. K	Zeitschrift für Krystallographie.
Z. P. G	Zeitschrift für Praktische Geologie. Berlin.
Fortieth Par	U. S. Geol. Expl. Fortieth Parallel. Washington.

CLASSIFIED LIST OF ANALYSES USED IN CONSTRUCTING DIAGRAMS.

CLASS I. PERSALANE.

Order 3. Columbare.

Rang 1. Alaskase.

Subrang 1. ——.

(I. 3, 1, 1.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
79.25	0.057	Porphyry	Harz Mountains	R. T., 1861, 7.

Subrang 2. Magdeburgose.

(I. 3, 1, 2.)

79.75	0.062	Quartz-porphyry	Blowing Rock, Watauga County, N. C.	Bull. 168, 52.— W. T.
78.86	.079	Felsite-porphyry	Fichtelgebirge, Bavaria	R. T., 1879, XX.
76.10	.085	Granite	Crystal Falls district, Mich	Bull. 168, 66.—W. T.
75.39	.080	Rhyolite	Silver Cliff, Colo	Bull. 168, 149.—W. T.
74.40	.079	Granite	Pikes Peak district, Colo	Bull. 168, 142.—W. T.

Subrang 3. Alaskose.

(I. 3, 1, 3.)

80.24	0.070	Granite	Wexford, Ireland	R. T., 1861-2.
79.57	.070	Rhyolite	Montgomery County, N. C	Bull. 168, 53.—W. T.
77.68	.077	Granitite	Eldorado County, Cal	Bull. 168, 199.—W. T.
77.68	.075 (77.6)	Quartz-porphyry	Tryberg Fall, Black Forest	N. J., 1883, II, 29.—W. T.
77.59	.059	Rhyolite	Hauraki Goldfield, New Zealand	Q. J. G. S., 1899, LV, 467.—W. T.
77.33	.079 (.078)	Alaskite	Tordrillo Mountains, Alaska	Bull. 168, 228.—W. T.
77.20	.080	Quartz-porphyry	Kroftkollen, Norway	Z. K., XVI, 77.—W. T.
77.05	.080	Aplite	Butte, Mont	Bull. 168, 118.—W. T.
77.03	.081 (76.8-.082)	Granitite	Pikes Peak district, Colo	Bull. 168, 142.—W. T.
77.02	.077 (77.1)	Granite	Platte Canyon, Colo	Bull. 168, 164.—W. T.
76.87	.078	Aplite	Butte, Mont	Bull. 168, 118.—W. T.
76.73	.077 (76.6)	Aplitic granophyre	Hennum, Norway	Z. K., XVI, 77.—W. T.
76.10	.063	Muscovite-granite	Omeo, Victoria	Trans. R. S. Vict.—W. T.
75.84	.081	Tordrillite	Tordrillo Mountains, Alaska	Bull. 168, 229.—W. T.
75.52	.080 (75.7)	Obsidian	Obsidian Cliff, Yellowstone Park	Bull. 168, 104.—W. T.
74.70	.083	.....do	.....do	Do.
74.24	.069	Rhyolite	Plumas County, Cal	Bull. 168, 178.—W. T.
73.11	.082 (73.0)	Pitchstone	Rosita, Colo	Bull. 168, 150.—W. T.

Subrang 4. ——.

(I. 3, 1, 4.)

83.08	0.054	Spherulitic rock	Wales	Teall, British Petrography, 339.
82.80	.049	Perlite	Monte Menone	R. T., 1869, XC.
76.00	.067	Granite	Plumas County, Cal	Bull. 168, 187.—W. T.
75.19	.076 (75.1)	Rhyolite	Madison Plateau, Yellowstone Park	Bull. 168, 105.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 5. WESTPHALOSE.

(I. 3, 1, 5.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
83.57	0.053	Quartz-keratophyre	Westphalia	N. J., 1893, VIII, 616.—W. T.
80.42	.059	.....do	.....do	N. J., 1893, VIII, 632.—W. T.
77.32	.081 (.083)	Granite	Roddö, Sweden	W. T.

RANG 2. ALSBACHASE.

SUBRANG 2. MIHALOSE.

(I. 3, 2, 2.)

73.15	0.055	Rhyolite	Nagy-Mihaly, Hungary	W. T.
73.07	.074	.....do	Washoe, Nev	Bull. 168, 174.—W. T.
72.68	.054	.....do	Nagy-Mihaly, Hungary	W. T.
70.59	.057	.....do	.....do	Do.

SUBRANG 3. TEHAMOSE.

(I. 3, 2, 3.)

79.95	0.049	Felsite-porphyry	Bohemia	R. T., 1884, XVIII.
77.34	.069	Aplite	Kirnechthal, Vosges	Rosenbusch, El., 207.
76.12	.059	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
75.89	.069 (75.8)	Rhyolite	Mount Sheridan, Yellowstone Park	Bull. 168, 105.—W. T.
75.34	.076	.....do	Elephants Back, Yellowstone Park	Do.
75.21	.072	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.65	.074	Rhyolite	Tehama County, Cal	Bull. 168, 178.—W. T.
74.41	.067	Granite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.34	.072	Rhyolite	Butte district, Mont	Bull. 168, 119.—W. T.
73.62	.079 (73.7)	.....do	Tehama County, Cal	Bull. 168, 178.—W. T.
72.37	.058	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
72.15	.067	.....do	.....do	Do.
72.04	.058	.....do	.....do	Do.
72.01	.073	Quartz-porphyry	Eureka, Nev	U. S. G. S., Mon. XX, 228.
71.45	.054	Granitite	Sykesville, Md	Bull. 168, 47.—W. T.

SUBRANG 4. ALSBACHOSE.

(I. 3, 2, 4.)

78.75	0.052	Granite	Storgord, Finland	R. T., 1869, XL.
77.85	.052	.....do	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.65	.064	Granitite	.....do	Do.
74.13	.077	Alsbachite	Melibocus, Odenwald	Rosenbusch, El., 207.—W. T.
73.08	.080 (72.9)	Rhyolite	Waihi, Hauraki, New Zealand	Q. J. G. S., 1899, LV, 467.—W. T.
72.89	.056	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.

SUBRANG 5. YUKONOSE.

(I. 3, 2, 5.)

74.79	0.067	Tonalite-aplite	Yukon River, Alaska	Bull. 168, 229.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. RIESENASE.

SUBRANG 2. ——.

(I. 3, 3, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
72.11	0.041	"Schliere" in granite	Riesengebirge, Silesia	N. J., 1898, XII, 235.—W. T.
71.14	.055	Toscanite	Rocca Strada, Italy	J. G., V, 363.—W. T.
66.86	.052	Granite-porphyry	Nieder Modau, Hesse	W. T.

SUBRANG 3. RIESENOSE.

(I. 3, 3, 3.)

76.82	0.037	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
75.27	.036	Granite	do	Do.
75.21	.048	Granitite	do	Do.
73.00	.049	Toscanite	Rocca Strada, Italy	J. G., V, 363.—W. T.
72.92	.040	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
72.71	.038	do	do	Do.
69.04	.047	do	do	N. J., 1898, XII, 234.—W. T.

SUBRANG 4. ——.

(I. 3, 3, 4.)

76.13	0.055 (76.2)	Granite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
72.81	.041	Granitite	do	N. J., 1898, XII, 232.—W. T.

SUBRANG 5. VULCANOSE.

(I. 3, 3, 5.)

72.24	0.062	Quartz-diorite-porphyry.	Calaveras County, Cal	Bull. 168, 203.—W. T.
66.99	.051	Vulcanite	Vulcano, Lipari	B. G. S. A., V, 601.—W. T.

RANG 4. ——.

SUBRANG 2. ——

(I. 3, 4, 2.)

68.87	0.028	"Schliere" in granite	Riesengebirge, Silesia	N. J., 1898, XII, 235.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 5. WESTPHALOSE.

(I. 3, 1, 5.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
83.57	0.053	Quartz-keratophyre	Westphalia	N. J., 1893, VIII, 616.—W. T.
80.42	.059	.....do	.....do	N. J., 1893, VIII, 632.—W. T.
77.32	.081 (.083)	Granite	Roddö, Sweden	W. T.

RANG 2. ALSBACHASE.

SUBRANG 2. MIHALOSE.

(I. 3, 2, 2.)

73.15	0.055	Rhyolite	Nagy-Mihaly, Hungary	W. T.
73.07	.074	.....do	Washoe, Nev	Bull. 168, 174.—W. T.
72.68	.054	.....do	Nagy-Mihaly, Hungary	W. T.
70.59	.057	.....do	.....do	Do.

SUBRANG 3. TEHAMOSE.

(I. 3, 2, 3.)

79.95	0.049	Felsite-porphyry	Bohemia	R. T., 1884, XVIII.
77.34	.069	Aplite	Kirnechthal, Vosges	Rosenbusch, El., 207.
76.12	.059	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
75.89	.069 (75.8)	Rhyolite	Mount Sheridan, Yellowstone Park	Bull. 168, 105.—W. T.
75.34	.076	.....do	Elephants Back, Yellowstone Park	Do.
75.21	.072	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.65	.074	Rhyolite	Tehama County, Cal	Bull. 168, 178.—W. T.
74.41	.067	Granite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.34	.072	Rhyolite	Butte district, Mont	Bull. 168, 119.—W. T.
73.62	.079 (73.7)	.....do	Tehama County, Cal	Bull. 168, 178.—W. T.
72.37	.058	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
72.15	.067	.....do	.....do	Do.
72.04	.058	.....do	.....do	Do.
72.01	.073	Quartz-porphyry	Eureka, Nev	U. S. G. S., Mon. XX, 228.
71.45	.054	Granitite	Sykesville, Md	Bull. 168, 47.—W. T.

SUBRANG 4. ALSBACHOSE.

(I. 3, 2, 4.)

78.75	0.052	Granite	Storgord, Finland	R. T., 1869, XL.
77.35	.052	.....do	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.65	.064	Granitite	.....do	Do.
74.13	.077	Alsbachite	Melibocus, Odenwald	Rosenbusch, El., 207.—W. T.
73.08	.080 (72.9)	Rhyolite	Waihi, Hauraki, New Zealand	Q. J. G. S., 1899, LV, 467.—W. T.
72.89	.056	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.

SUBRANG 5. YUKONOSE.

(I. 3, 2, 5.)

74.79	0.067	Tonalite-aplite	Yukon River, Alaska	Bull. 168, 229.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. RIESENASE.

SUBRANG 2. ——.

(I. 3, 3, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
72.11	0.041	"Schliere" in granite	Riesengebirge, Silesia	N. J., 1898, XII, 235.—W. T.
71.14	.055	Toscanite	Rocca Strada, Italy	J. G., V, 363.—W. T.
66.86	.052	Granite-porphyry	Nieder Modau, Hesse	W. T.

SUBRANG 3. RIESENOSE.

(I. 3, 3, 3.)

76.82	0.037	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
75.27	.036	Granite	do	Do.
75.21	.048	Granitite	do	Do.
78.00	.049	Toscanite	Rocca Strada, Italy	J. G., V, 363.—W. T.
72.92	.040	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
72.71	.038	do	do	Do.
69.04	.047	do	do	N. J., 1898, XII, 234.—W. T.

SUBRANG 4. ——.

(I. 3, 3, 4.)

76.13	0.055 (76.2)	Granite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
72.81	.041	Granitite	do	N. J., 1898, XII, 232.—W. T.

SUBRANG 5. VULCANOSE.

(I. 3, 3, 5.)

72.24	0.062	Quartz-diorite-porphyry.	Calaveras County, Cal	Bull. 168, 203.—W. T.
66.99	.051	Vulcanite	Vulcano, Lipari	B. G. S. A., V, 601.—W. T.

RANG 4. ——.

SUBRANG 2. ——

(I. 3, 4, 2.)

68.87	0.028	"Schliere" in granite	Riesengebirge, Silesia	N. J., 1898, XII, 235.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

ORDER 4. BRITANNARE.

RANG 1. LIPARASE.

SUBRANG 1. LEBACHOSE.

(I. 4, 1, 1.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
69.06	0.117 (69.3)	Quartz-orthoclasite...	Thüringerwald, Prussia..............	W. T.
68.13	.107	Quartz-porphyry	Hummelberg, Prussia................	Do.

SUBRANG 2. OMEOSE.

(I. 4, 1, 2.)

75.20	0.096	Rhyolite	Silver Cliff, Colo.......................	Bull. 168, 149.—W. T.
75.07	.084	.....do	Pine Nut Canyon, Nev	Fortieth Par., I, 652.
74.62	.095	.....do	Humboldt Sink Group, Nev..........	Do.
74.24	.089	Rapakiwi	Livland, Finland......................	R. T., 1878, X.
71.09	.112	Aplite	Satteljoch, Predazzo, Tyrol	K. A. W. W., CXI, I, 266.
70.91	.121	Graphic granite	Omeo, Victoria.........................	Trans. R. S. Vict.—W. T.
68.99	.115	Pitchstone	Ponza, Italy...........................	R. T., 1879, LII.
68.87	.084	Granite...............	Omeo, Victoria.........................	Trans. R. S. Vict.—W. T.

SUBRANG 3. LIPAROSE.

(I. 4, 1, 3.)

77.61	0.088	Granite...............	Cape Ann, Mass.......................	J. G. VI, 793.—W. T.
76.49	.092	Paisanite.............	Magnolia, Mass........................	J. G. VII, 113.—W. T.
76.33	.092	Graphic granite	Hochland	R. T., 1869, XLII.
76.30	.088	Alaskite..............	Alaska	Bull. 168, 228.—W. T.
76.20	.091	Obsidian	Obsidian Hill, N. Mex................	Bull. 168, 172.—W. T.
76.05	.092	Aplitic granophyre...	Konerudwege, Norway................	Z. K., XVI, 77.—W. T.
75.71	.094 (75.6)	Rhyolite	Great Paint Pots, Yellowstone Park..	Bull. 168, 105.—W. T.
75.44	.094	Comendite	Iskagan Bay, Siberia..................	A. J. S., XII, 1902, 180.—W. T.
75.44	.089	Rhyolite	Fish Creek Mountains, Nev	Fortieth Par., I, 652.
75.30	.082	.....do	Rimini, Mont	Bull. 168, 119.—W. T.
75.17	.085	Granitite	Pikes Peak district, Colo......... ...	Bull. 168, 142.—W. T.
74.90	.094	Rhyolite..............	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
74.87	.084	Granite...............	Brookville, Md.........................	Bull. 168, 46.—W. T.
74.76	.098	Comendite	Comende, San Pietro, Sardinia.......	Rosenbusch, El., 257.—W. T.
74.45	.090	Rhyolite..............	Chalk Mountain, Colo	Bull. 168, 156.—W. T.
74.05	.096	Obsidian	Mono Craters, Cal.....................	Bull. 168, 219.—W. T.
73.93	.100	Granite...............	Quincy, Mass..........................	J. G., VI, 793.—W. T.
73.69	.100	Granite-porphyry.....	Mount Ascutney, Vt	Bull. 168, 25.—W. T.
73.51	.094 (73.4)	Granitite	Pikes Peak district, Colo.............	Bull. 168, 142.—W. T.
73.35	.106	Paisanite.............	Mosques Canyon, Tex.................	T. M. P. M., XV, 439.—W. T.
73.09	.085	Granite-porphyry.....	Albany, N. H...........................	A. J. S., XX, 1881, 25.
73.03	.104	Syenite-porphyry.....	Mount Ascutney, Vt..................	Bull. 168, 24.—W. T.
72.88	.093	Aplite-granite	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
72.48	.099	Granite...............	.....do	Do.
72.35	.093	.....do	Ironton, Mo	Bull. 168, 60.—W. T.
72.26	.101	.....do	Albany, N. H...........................	A. J. S., XXI, 1881, 25.
72.06	.107	.....do	Stony Creek, Conn	B. G. S. A., X, 375.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

Subrang 3. Liparose—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
71.90	.102	Granitite	Mount Ascutney, Vt	Bull. 168, 24.—W. T.
71.88	.095	Porphyry	Ironton, Mo	Bull. 168, 60.—W. T.
71.67	.101	Quartz-porphyry	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
71.56	.086	Pitchstone	Silver Cliff, Colo	Bull. 168, 159.—W. T.
71.49	.109	Quartz-porphyry	Gislerud, Norway	Z. K., XVI, 46.—W. T.
71.07	.087	Granite-porphyry	Albany, N. H	A. J. S., XXI, 1881, 25.
70.92	.096 (70.7)	Rhyolite	Upper Geyser Basin, Yellowstone Park.	Bull. 168, 104.—W. T.
70.23	.113	Keratophyre	Marblehead Neck, Mass	Bull. 168, 34.—W. T.
70.09	.092	Orthoclase-porphyry	Cornon, Tyrol	R. T., 1879, XXVIII.
70.01	.113	Obsidian	Palmerola, Italy	R. T., 1879, LII.
69.91	.119	Ægirite-granite	Miask, Ural Mountains	A. J. S., XIII, 1902, 180.—W. T.
69.89	.098	Rhyolite	Nathrop, Colo	Bull. 168, 164.—W. T.
68.95	.144	Grorudite	W. Aker, Norway	E. K., I, 199.—W. T.
68.71	.114	Quartz-pantellerite	Vieja Mountains, San Carlos, Tex	Bull. 168, 61.—W. T.
68.65	.110 (68.5)	Granite-syenite-porphyry.	Little Rocky Mountains, Mont	Bull. 168, 134.—W. T.
68.34	.129	Quartz-syenite	Bearpaw Mountains, Mont	Bull. 68, 135.—W. T.
66.40	.097 (66.7)	Quartz-syenite-porphyry.	Fjelebua, Norway	Z. K., XVI, 46.—W. T.

Subrang 4. Kallerudose.

(I. 4, 1, 4.)

75.92	0.093 (75.8–.094)	Granitite	Pikes Peak district, Colo	Bull. 168, 142.—W. T.
73.61	.089	Rhyolite	Oyacachi, South America	R. T., 1879, LIV.
73.50	.095 (73.8)	Quartz-bearing bostonite.	Ampangarinana, Madagascar	M. M., 55.
72.56	.099 (72.8)	Rhyolitic pitchstone	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
72.46	.095	Rhyolite	Guomani, Ecuador, South America	R. T., 1879, LIV.
71.65	.119	Soda granite	Hougnatten, Norway	E. K., I, 198.—W. T.

Subrang 5. Noyangose.

(I. 4, 1, 5.)

77.66	0.087 (77.9–.086)	Quartz-keratophyre	Omeo, Victoria	Rosenbusch, El., 260.—W. T.
75.78	.091	Granite	Rice Point, Duluth, Minn	21st Ann. Rept., Surv. Minn., 41.—W. T.
75.46	.097	Soda-rhyolite	Berkeley, Cal	Rosenbusch, El., 260.—W. T.

Rang 2. Toscanase.

Subrang 2. Dellenose.

(I. 4, 2, 2.)

69.19	0.102	Granite	Tryberg Fall, Schwarzwald	N. J., 1883, II.
68.36	.078	Dellenite	Dellen, Helsingland, Sweden	E. K., II, 59.—W. T.
66.24	.093	Toscanite	Monte Cucco, Italy	J. G., V, 362.—W. T.
65.19	.093	.....do	Tolfa, Italy	Do.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. TOSCANOSE.

(I. 4, 2, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
76.48	0.087	Aplite	Dargo, Victoria	Trans. R. S. Vict.—W. T.
76.03	.081	.....do	Sierra County, Cal	Bull. 168, 192.—W. T.
76.00	.087	Granodiorite-aplite	Downieville area, Cal	J. G., VII, 160.—W. T.
75.97	.079 (76.1-.078)	Aplite	Sierra County, Cal	Bull. 168, 192.—W. T.
75.74	.086	Granite	Lier, Norway	Z. K., XVI, 77.—W. T.
75.08	.084 (75.0)	Obsidian	Laguna de Maricunga, Chile	Z. D. J., G. LI, 4.
75.01	.086 (75.1-.088)	Alaskite	Alaska	Bull. 168, 228.—W. T.
74.95	.088	Rhyolite	Montezuma Mountains, Nev	Fortieth Par., I, 652.
74.60	.081	.....do	Shasta County, Cal	Bull. 168, 178.—W. T.
74.49	.088 (74.6)	.....do	Thomas Range, Utah	Bull. 168, 168.—W. T.
74.37	.085	Granitite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
73.84	.083	Rhyolite-perlite	Midway Basin, Yellowstone Park	Bull. 168, 108.—W. T.
73.70	.092	Granite	Peterhead, Scotland	R. T., 1884, XIV.
73.64	.083	Rhyolite	Lassen trail, Tehama County, Cal	Bull. 168, 178.—W. T.
73.51	.097	Obsidian	Modoc County, Cal	Bull. 168, 217.—W. T.
73.38	.080	Granite	Lake Raslangen, Sweden	W. T.
73.12	.087	Quartz-porphyry	Little Belt Mountains, Mont	Bull. 168, 125.—W. T.
72.57	.090	Granite	Guilford, Md	Bull. 168, 46.—W. T.
72.40	.086	Rhyolite	Mount Stover, Cal	Bull. 168, 178.—W. T.
71.85	.087 (72.0)	.....do	Tower Creek, Yellowstone Park	Bull. 168, 104.—W. T.
71.79	.082 (71.7)	Granitite	Woodstock, Md	Bull. 168, 46.—W. T.
71.78	.085	Granite	Cottonwood Canyon, Utah	Fortieth Par., I, 110.
71.53	.070	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
71.12	.098	Rhyolite	Ponza, Italy	R. T., 1879, LII.
71.08	.084 (71.0)	Granodiorite	El Capitan, Yosemite, Cal	Bull. 168, 207.—W. T.
70.87	.092	Rhyolite	Pennsylvania Hill, Silver Cliff, Colo	Bull. 168, 149.—W. T.
70.75	.080	Granite	Amador County, Cal	Bull. 168, 200.—W. T.
70.56	.105 (70.7)	Rhyolite	Ponza, Italy	
70.54	.107	Ægirite-granite	Löken, Norway	Z. K., XVI, 57.—W. T.
70.45	.084	Granite	Dorseys Run, Md	Bull. 168, 47.—W. T.
70.29	.101	Rhyolite	Harlequin Canyon, Nev	Fortieth Par., I, 652.
69.96	.089	Dacite	Washoe, Nev	Bull. 168, 174.—W. T.
69.95	.098 (70.1)	Quartz-porphyry	Butte district, Mont	Bull. 168, 119.—W. T.
69.94	.092	Granite	Ironton, Mo	Bull. 168, 60.—W. T.
69.68	.087	Granite-porphyry	Little Belt Mountains, Mont	Bull. 168, 125.—W. T.
69.52	.108	Trachyte	Pikes Peak district, Colo	Bull. 168, 145.—W. T.
69.45	.097	Rhyolo-trachyte	Sunset Peak, Mont	Bull. 168, 106.—W. T.
68.88	.100	Quartz-syenite-porphyry.	Squam Light, Mass	J. G., VII, 109.—W. T.
68.68	.077	Granite	Eureka, Nev	U. S. G. S., Mon. XX, 228.
68.60	.107 (68.7)	Granite-porphyry	Little Belt Mountains, Mont	Bull. 168, 125.—W. T.
68.58	.100	Granite	West Humboldt Mountains, Nev	Fortieth Par., I, 110.
68.55	.095	.....do	Shap, England	Q. J. G. S., 47, 276
68.42	.083 (68.2)	Quartz-monzonite	Hailey, Idaho	Bull. 168, 137.—W. T.
68.40	.112 (68.2)	Granite	Millstone Point, Conn	B. G. S. A., X, 375.—W. T.
68.36	.105	Nordmarkite	Gloucester, Mass	J. G., VI, 800.—W. T.
67.45	.084	Granodiorite	Eldorado Canyon, Cal	Bull. 168, 199.—W. T.
67.44	.104	Granite-syenite-porphyry.	Little Belt Mountains, Mont	Bull. 168, 127.—W. T.
67.12	.082	Granite	Boulder, Mont	Bull. 168, 118.—W. T.
67.04	.107	Quartz-syenite-porphyry.	Little Belt Mountains, Mont	Bull. 168, 127.—W. T.
66.60	.111	Akerite	Gloucester, Mass	J. G., VI, 798.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. TOSCANOSE—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.12	.123 (66.3)	Trachyte	Wicher Mountain, Colo	Bull. 168, 145.—W. T.
65.58	.094	.....do	Monte Amiata, Italy	Rosenbusch, El., 269.—W. T.
65.32	.096	.....do	.....do	Do.
65.05	.092	Toscanite	.....do	J. G., V, 362.—W. T.
64.76	.094	Trachyte	.....do	Rosenbusch, El., 269.—W. T.
64.64	.114 (64.5)	Syenite	Little Belt Mountains, Mont	Bull. 168, 125.—W. T.
64.62	.118	Diorite	Mount Ascutney, Vt	Bull. 168, 25.—W. T.
64.57	.095	Toscanite	Bracciano, Italy	J. G., V, 362.—W. T.
64.49	.103	Porphyrite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
62.33	.110	Latite	Clover Meadow, Tuolumne County, Cal.	Bull. 168, 205.—W. T.

SUBRANG 4. LASSENOSE.

(I. 4, 2, 4.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
75.50	0.083	Rhyolite	Obsidian Cliff, Yellowstone Park	Bull. 168, 104.—W. T.
73.27	.077	Granite	Florence, Mass	Bull. 168, 30.—W. T.
73.00	.075	.....do	Rocklin, Cal	Bull. 168, 198.—W. T.
72.59	.083	Obsidian	Willow Park, Yellowstone Park	Bull. 168, 104.—W. T.
71.74	.075	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
71.19	.073	Quartz-porphyrite	Calaveras County, Cal	Bull. 168, 203.—W. T.
70.36	.082	Granodiorite	Enterprise, Butte County, Cal	Bull. 168, 190.—W. T.
69.93	.109	Granite-porphyry	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
69.66	.084	Dacite	Lassen Peak, Cal	Fortieth Par., I, 652.
69.56	.076	.....do	Colombia, South America	J. G., I, 171.—W. T.
69.51	.083	.....do	Lassen Peak, Cal	Bull. 168, 179.—W. T.
69.00	.126	Quartz-lindoite	W. Aker, Norway	E. K., I, 196.—W. T.
68.72	.084 (68.8)	Dacite	Lassen Peak, Cal	Bull. 168, 180.—W. T.
68.65	.084	Quartz-monzonite	Sierra County, Cal	Bull. 168, 192.—W. T.
68.32	.086	Dacite	Lassen Peak, Cal	Bull. 168, 179.—W. T.
68.10	.088	.....do	Shasta County, Cal	Bull. 168, 180.—W. T.
67.89	.088	Andesite	Buntingville, Cal	Bull. 168, 181.—W. T.
67.55	.087 (67.2)	Pitchstone	Butte district, Mont	Bull. 168, 119.—W. T.
67.49	.085 (67.6)	Dacite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
67.49	.112	Mica-dacite	Silver Cliff, Colo	Bull. 168, 149.—W. T.
67.42	.116	Augite-soda-granite	Kekequabic Lake, Minn	A. G., XI, 385.—W. T.
67.01	.120	Alaskite-porphyry	Alaska	Bull. 168, 228.—W. T.
66.46	.104	Dacite	Rosita, Colo	Bull. 168, 149.—W. T.
66.30	.098	Dacite-porphyry	Shasta County, Cal	Bull. 168, 177.—W. T.
66.28	.094 (66.5)	Porphyrite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
65.87	.099	Feldspar-porphyry	Castle Mountain district, Mont	Bull. 168, 130.—W. T.
65.78	.121	Mica-andesite	San Mateo Mountain, N. Mex	Bull. 168, 170.—W. T.
65.64	.106	Andesite-porphyry	Gray Peak, Yellowstone Park	Bull. 168, 107.—W. T.
64.98	.109	Oligoclasite	Preston, Norway	B. M. A., 1898, VII, 47.—W. T.
62.58	.109	Syenite-porphyry	Yogo Peak, Mont	Bull. 168, 127.—W. T.

SUBRANG 5. MARIPOSOSE.

(I. 4, 2, 5.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
74.21	0.100	Soda-granite	Mariposa County, Cal	Bull. 168, 207.—W. T.
67.88	.084 (67.8)	Granite	Cavaura River, British Guiana	W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. COLORADASE.

SUBRANG 3. AMIATOSE.

(I. 4, 3, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
68.97	0.075	Granite	Lower Elsass, Vosges	Rosenbusch, El., 78.
65.53	.085	Trachyte	Monte Amiate, Italy	Rosenbusch, El., 269.—W. T.
65.36	.085	Quartz-porphyrite	Mount Carbon, Colo	Bull. 168, 160.—W. T.
65.18	.082	Andesite-perlite	Eureka, Nev	U. S. G. S., Mon. XX, 264.—W. T.
63.17	.088	Dacite	Pergamon, Asia Minor	A. J. S., III, 1897, 45.—W. T.
61.93	.085	Andesite	Kara Tash, Asia Minor	A. J. S., III, 1897, 45.—W. T.

SUBRANG 4. YELLOWSTONOSE.

(I. 4, 3, 4.)

68.41	0.084	Dacite	Colombia, South America	J. G., I, 171.—W. T.
68.10	.065	Diorite	Ono, Cal	Bull. 168, 177.—W. T.
68.12	.078	Andesite	Shasta County, Cal	Bull. 168, 183.—W. T.
67.30	.075	Dacite	Colombia, South America	J. G., I, 171.—W. T.
66.94	.070	Andesite	Sierra County, Cal	Bull. 168, 193.—W. T.
66.65	.082	Quartz-diorite-porphyry.	.....do	Bull. 168, 192.—W. T.
66.65	.074	Granodiorite	Nevada City, Cal	Bull. 168, 194.—W. T.
65.71	.065	Banatite	Banat, Hungary	Rosenbusch, El., 140.
65.66	.072	Dacite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
65.63	.080	Andesite	Fan Creek, Yellowstone Park	Bull. 168, 107.—W. T.
65.60	.086 (65.7)	Quartz-mica-diorite	Electric Peak, Yellowstone Park	Bull. 168, 88.—W. T.
64.85	.084	.....do	.....do	Do.
64.61	.088	Andesite	Crescent Hill, Yellowstone Park	Bull. 168, 108.—W. T.
64.52	.080	.....do	Mount Shasta, Cal	Bull. 168, 176.—W. T.
64.48	.076 (64.7)	.....do	.....do	Do.
64.27	.081	.....do	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
64.24	.075 (64.1)	Dacite-porphyry	Shasta County, Cal	Bull. 168, 177.—W. T.
63.81	.079	Dacite	Mill Creek, Shasta County, Cal	Bull. 168, 180.—W. T.
63.42	.098	Quartz-diorite-porphyry.	Crandall Basin, Wyo	Bull. 168, 94.—W. T.
63.30	.087	Andesite	Mount Rose, Washoe, Nev	Fortieth Par. I, 604.
62.91	.094	Granitite	Dorseys Run, Md	Bull. 168, 47.—W. T.
62.85	.085	(?) Porphyrite-diorite	Mount Marcellina, Colo	Bull. 168, 160.—W. T.
61.42	.078	Porphyrite	Storm Ridge, Colo	Do.

SUBRANG 5. AMADOROSE.

(I. 4, 3, 5.)

69.66	0.074	Quartz-diorite-aplite	Amador County, Cal	Bull. 168, 201.—W. T.
69.34	.066	Granite	Saganaga Lake, Minn	21st Ann. Rept. Geol. Surv. Minn., 43.—W. T.

RANG 4. ——.

SUBRANG 3. ——.

(I. 4, 4, 3.)

65.81	0.047	Granite	Hochwald, Vosges	Rosenbusch, Steiger Schiefer (Strassburg, 1877), 167.

Classified list of analyses used in constructing diagrams—Continued.

ORDER 5. CANADARE.

RANG 1. NORDMARKASE.

SUBRANG 3. PHLEGROSE.

(I. 5, 1, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.13	0.130	Quartz-syenite	Fjelebua, Norway	Z. K., XVI, 46.—W. T.
66.03	.132 (65.9)	Trachyte	Game Ridge, Custer County, Colo	Bull. 168, 147.—W. T.
65.43	.131	Syenite	Mount Ascutney, Vt	Bull. 168, 24.—W. T.
64.88	.128	Syenite-porphyry	do	Bull. 168, 25.—W. T.
64.04	.160	Nordmarkite	Tonsenas, Norway	Z. K., XVI, 54.—W. T.
63.71	.159	Pulaskite	Salem Neck, Mass	J. G., VI, 806.—W. T.
62.30	.142	Bostonite	Gran, Norway	E. K., III, 204.—W. T.
61.92	.151	Pulaskite	Lokobé, Madagascar	M. M., 204.
61.88	.176	Trachyte	Marecocco, Italy	A. J. S., VIII, 1899, 289.—W. T.
61.62	.170 (61.2)	do	Monte Rotaro, Italy	Do.
61.45	.143 (61.3)	do	Maros, Celebes	G. C., 16.
61.05	.166	Sölvsbergite	Coney Island, Mass	J. G., VII, 118.—W. T.
60.33	.193	Trachyte	Monte Nuovo, Italy	A. J. S., VIII, 1899, 287.—W. T.
60.13	.165	Nephelite-syenite	Fourche Mountain, Ark	J. G., IX, 610.—W. T.
60.02	.147	Syenite-keratophyre	Harz Mountains	R. T., 1884, XXII.
59.79	.186	Trachyte	Monte Nuovo, Italy	A. J. S., VIII, 1899, 287.—W. T.
59.70	.164	Nephelite-syenite	Fourche Mountain, Ark	I. R. A., 88.—W. T.
58.75	.176	Umptekite	Cabo Frio, Brazil	T. M. P. M., XX, 248.—W. T.
57.18	.171	Trachyte	Highwood Mountains, Mont	Bull. 168, 131.—W. T.

SUBRANG 4. NORDMARKOSE.

(I. 5, 1, 4.)

66.50	0.162	Lestiwarite	Kvella, Norway	E. K., III, 216.—W. T.
66.22	.149 (66.4)	Quartz-syenite-porphyry.	Bearpaw Mountains, Mont	Bull. 168, 135.—W. T.
66.06	.151	Liparite	Hohenburg, near Bonn, Prussia	R. T., 1884, XLVIII.
65.51	.143	Phonolitic andesite	San Mateo Mountains, N. Mex	Bull. 168, 170.—W. T.
65.43	.140 (65.1)	Nordmarkite	Shefford Mountain, Quebec	J. G., XI, 271.
64.92	.146	Quartz-sölvsbergite	Gran, Norway	E. K., I, 78.—W. T.
64.54	.157	Pulaskite	Lovasbucht, Norway	E. K., III, 198.—W. T.
64.33	.151	Acmite-trachyte	Crazy Mountains, Mont	Bull. 168, 123.—W. T.
63.76	.161 (63.4)	Syenite	Ahvenvaara, Finland	B. C. G. F., 11, 34.—W. T.
63.20	.161	Nordmarkite	Tonsenas, Norway	Z. K., XVI, 54.—W. T.
63.09	.164 (63.6)	Pulaskite	Salem Neck, Mass	J. G., VI, 806.—W. T.
62.17	.156	Acmite-trachyte	Crazy Mountains, Mont	Bull. 168, 123.—W. T.
61.67	.169	Keratophyre	Harz Mountains	R. T., 1884, XXII.
61.54	.180	Phonolite	Zittau, Saxony	R. T., 1861, 23.
61.08	.185	do	Black Hills, S. Dak	A. J. S., XLVII, 1894, 344.—W. T.
60.39	.184	Litchfieldite	Litchfield, Me	Bull. 168, 21.—W. T.
60.11	.161 (59.9)	Bostonite	Hedrum, Norway	E. K., III, 204.—W. T.
60.05	.157 (60.3)	Tinguaite	Gales Point, Mass	J. G., VII, 481.—W. T.
59.62	.173	Nephelite-syenite	Saline County, Ark	I. R. A., 135.—W. T.
59.31	.174	Foyaite	Great Haste Island, Mass	J. G., VII, 481.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 5. TUOLUMNOSE.

(I, 5, 1, 5.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
67.58	0.165	Albitite	Tuolumne County, Cal	Bull. 168, 204.—W. T.
66.09	.162	do	Koswinsky, Ural Mountains	O. N., 169.

RANG 2. PULASKASE.

SUBRANG 2. VULSINOSE.

(I. 5, 2, 2.)

58.48	0.165	Leucite-trachyte (?)	Rocca Monfina, Italy	J. G., V, 370 —W. T.
58.21	.142	Vulsinite	Bolsena Monfina, Italy	J. G., V, 358.—W. T.
57.32	.156	do	Vetrella, Italy	Do.
55.17	.150	Leucite-trachyte	San Rocco, Italy	J. G., V, 370.—W. T.

SUBRANG 3. PULASKOSE.

(I. 5, 2, 3.)

65.54	0.135	Quartz-syenite	Highwood Mountains, Mont	W. T.
62.64	.119	Andesite (?)	Pikes Peak district, Colo	Bull. 168, 145.—W. T.
61.87	.145	Trachyte	Ischia, Italy	R. T., 1873, XXXVIII.
61.55	.141	do	do	R. T., 1873, XXXVI.
60.89	.131	Quartz-banakite	Ishawooa Canyon, Wyo	Bull. 168, 102.—W. T.
60.20	.165	Pulaskite	Fourche Mountain, Ark	J. G., IX, 609.—W. T.
60.03	.154	do	do	I. R. A., 88.—W. T.
59.51	.158	Leucite-trachyte	Viterbo, Italy	J. G., V, 370.—W. T.
59.23	.149	Nephelite-syenite	Fourche Mountain, Ark	I. R. A., 88.—W. T.
57.15	.149	Trachy-dolerite	Maros, Celebes	G. C., 14.
56.45	.175	Sodalite-syenite	Square Butte, Mont	Bull. 168, 134.—W. T.
55.52	.146	Bostonite	Gentungen, Celebes	G. C., 20.

SUBRANG 4. LAURVIKOSE.

(I. 5, 2, 4.)

65.41	0.139	Trachyte	Game Ridge, Custer County, Colo	Bull. 168, 147.—W. T.
64.80	.125	Domite	Puy de Dome, France	R. T., 1869, CXVIII.
64.63	.132	Quartz-syenite	Fourche Mountain, Ark	I. R. A., 96.—W. T.
63.49	.133	Andesite	Custer County, Colo	Bull. 168, 148.—W. T.
61.47	.120	do	Pantellaria, Italy	Z. K., VIII, 155.
61.43	.133	do	do	Z. K., VIII, 164.
61.05	.147	Trachyte	Ischia, Italy	R. T., 1873, XXXVIII.
60.98	.142 (59.9)	Augite-porphyrite	Henry Mountains, Utah	Bull. 168, 167.—W. T.
60.72	.142	Rhombenporphyry	Nötterö, Norway	Z. K., XVI, 35.—W. T.
60.45	.168	Nordmarkite	Aneröd, Norway	Z. K., XVI, 54.—W. T.
60.24	.170	Augite-andesite	Pantellaria	Z. K., VIII, 155.
59.96	.165	Pulaskite	Shefford Mountain, Quebec	J. G., XI, 271.
59.38	.125	Tönsbergite	Tönsberg, Norway	E. K., III, 375.—W. T.
58.94	.109	Andesite	Silver Cliff, Colo	Bull. 168, 148.—W. T.
58.88	.141	Laurvikite	Laurvik, Norway	Z. K., XVI, 30.—W. T.
58.82	.155	Rhombenporphyry	Tönsberg, Norway	Z. K., XVI, 35.—W. T.
57.59	.139	do	Nötterö, Norway	Do.
57.44	.157	Pulaskite	Mount Johnson, Quebec	J. G., XI, 271.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 4. LAURVIKROSE—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
57.33	.153 (57.1)	Rhombenporphyry...	Nötterö, Norway	Z. K., XVI, 35.—W. T.
57.12	.138	Laurvikite	Fredriksvärn, Norway	Z. K., XVI, 30.—W. T.
56.85	.144	.....do	Nötterö, Norway	Do.
56.25	.155 (55.9)	Micromonzonite	Ambodimadiro, Madagascar	M. M., 204.
56.19	.156	Tephritic trachyte	Columbretes Islands, Spain	T. M. P. M., XVI, 314.—W. T.
54.00	.162	Rhombenporphyry...	Brumunthal, Norway	Z. K., XVI, 28.—W. T.

SUBRANG 5. ——.

(I. 5, 2, 5.)

62.90	0.135	Diorite	Jablanica, Herzegovina	W. T.
60.13	.164	Keratophyre	New Haven, Conn	A. J. S., III, 1897, 291.—W. T.

RANG 3. ——.

SUBRANG 2. ——.

(I. 5, 3, 2.)

59.33	0.135 (59.5)	Augite-syenite	Mazaruni district, British Guiana	W. T.

SUBRANG 3. ——.

(I. 5, 3, 3.)

59.26	0.139	Andesite	Table Mountain, Colo	Bull. 168, 141.—W. T.

SUBRANG 4. ——.

(I. 5, 3, 4.)

58.28	0.112	Diabase-porphyrite...	Crazy Mountains, Mont	Bull. 168, 121.—W. T.

RANG 4. LABRADORASE.

SUBRANG 3. LABRADOROSE.

(I. 5, 4, 3.)

55.01	0.086	Anorthosite	Turtschinka, Wolynien, Russia	W. T.
54.62	.093	.....do	New York State	N. J., 1893, VIII, 494.
54.45	.122	.....do	Rawdon, Canada	Do.
53.53	.090 (53.6)	.....do	Pököla, Finland	W. T.
53.43	.099	.....do	Labrador, Canada	N. J., 1893, VIII. 494.—W. T.
53.42	.096	.....do	Ogne, Norway	B. M. A., 1896, V, 96.—W. T.
52.61	.092	.....do	Ekersund, Norway	B. M. A., 1896, V, 79.—W. T.
49.78	.091	.....do	Carlton Peak, Minn	Am. Geol., XXVI, 281.—W. T.
47.25	.056	.....do	Beaver Bay, Lake Superior	U. S. G. S., Mon. V, 438.

RANG 5. CANADASE.

(I. 5, 5.)

47.32	0.048 (47.4)	Anorthosite	South Sherbrooke, Ontario	Am. Geol., XXIV, 280.—W. T.
46.24	.044	.....do	Seine River, Canada	J. G., IV, 909.—W. T.
45.78	.036	.....do	Monhegan Isle, Me	Am. Geol., XXVI, 340.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

Rang 4. ———.

Subrang 3. ——.

(II. 3, 4, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.88	0.020	Quartz-diorite	Little Falls, Minn	R. T., 1879, XXXVI.

Order 4. Austrare.

Rang 1. Pantellerase.

Subrang 3. Grorudose.

(II. 4, 1, 3.)

70.15	0.109	Grorudite	Grusletten, Norway	E. K., I, 199.—W. T.
69.61	.129	Pantellerite	Pantellaria	Z. K., VIII, 173.—W. T.
69.02	.121	do	do	Z. K., VIII, 182.—W. T.
68.33	.137	do	do	Z. K., VIII, 170.—W. T.
66.50	.123	Grorudite	Grusletten, Norway	E. K., I, 199.—W. T.
61.83	.102 (62.2)	Porphyrite	Süpplingen, Magdeburg, Prussia	W. T.

Subrang 4. Pantellerose.

(II. 4, 1, 4.)

71.35	0.116	Grorudite	Kallerud, Norway	E. K., I, 199.—W. T.
67.89	.116	Pantellerite	Pantellaria	Z. K., VIII, 186.—W. T.
67.48	.131	do	do	Do.
67.18	.122	do	do	Do.

Rang 2. Dacase.

Subrang 3. Adamellose.

(II. 4, 2, 3.)

66.57	0.103	Granite-porphyry	Kirche Wang, Silesia	Rosenbusch, El., 195.
63.97	.105	Quartz-mica-diorite	Crandall Basin, Wyo	Bull. 168, 94.—W. T.
62.51	.090	Syenite	Reichenstein, Silesia	N. J., 1890, I, 206.—W. T.
61.93	.104	Granitite	Laveline, Vosges	Rosenbusch, El., 78.
59.24	.095 (59.5)	Trachyte-andesite	Highwood Mountains, Mont	Bull. 168, 131.—W. T.

Subrang 4. Dacose.

(II. 4, 2, 4.)

65.50	0.107	Andesite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
64.47	.098	Granitite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
63.50	.101	Dacite	Chiles, Colombia, South America	J. G., I, 171.—W. T.
61.56	.102	Andesite	Tower Creek, Yellowstone Park	Bull. 168, 108.—W. T.
56.59	.088	Quartz-diorite	Sauk Center, Minn	R. T., 1879, XXXIV.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 5. MARIUPOLOSE.

(I. 6, 1, 5.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
60.29	0.197 (60.5)	Mariupolite	Nikolajew, Russia	T. M. P. M., XXI, 244.—W. T.

RANG 2. VIEZZENASE.

SUBRANG 3. ——.

(I. 6, 2, 3.)

53.76	0.207 (53.6)	Nephelite-tinguaite	Magnet Cove, Ark	I. R. A., 266.—W. T.

SUBRANG 4. VIEZZENOSE.

(I. 6, 2, 4.)

56.04	0.201	Nephlite-rhomben-porphyry.	Vasvik tunnel, Norway	Z. K., XVI, 38.—W. T.
55.40	.184	Andesite	Palma, Sicily	R. T., 1879, LXVI.
54.68	.176	Nephelite-syenite	Brookville, N. J	Bull. 168, 39.—W. T.
54.61	.197	do	Caldas de Monchique, Portugal	N. J., B. B., III, 271.—W. T.
54.46	.186	Tinguaite	Umptek, Kola, Finland	Rosenbusch, El., 215.—W. T.

ORDER 7. TASMANARE.

RANG 1. LAUGENASE.

SUBRANG 4. LAUGENOSE.

(I. 7, 1, 4.)

55.50	0.248	Foyaite	Brathagen, Norway	E. K., III, 176.—W. T.

CLASS II. DOSALANE.

ORDER 3. HISPANARE.

RANG 1. VARINGASE.

SUBRANG 3. VARINGOSE.

(II. 3, 1, 3.)

74.35	0.092	Grorudite	Varingskollen, Norway	Z. K., XVI, 66.—W. T.
70.30	.128	Pantellerite	Pantellaria	Z. K., VIII, 173.—W. T.

SUBRANG 4. ——.

(II. 3, 1, 4.)

72.12	0.070	Felsite	Cudgegong River, New South Wales, Australia.	W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 4. ———.

SUBRANG 3. ———.

(II. 3, 4, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.88	0.020	Quartz-diorite	Little Falls, Minn	R. T., 1879, XXXVI.

ORDER 4. AUSTRARE.

RANG 1. PANTELLERASE.

SUBRANG 3. GRORUDOSE.

(II. 4, 1, 3.)

70.15	0.109	Grorudite	Grussletten, Norway	E. K., I, 199.—W. T.
69.61	.129	Pantellerite	Pantellaria	Z. K., VIII, 173.—W. T.
69.02	.121	.....do	.....do	Z. K., VIII, 182.—W. T.
68.33	.137	.....do	.....do	Z. K., VIII, 170.—W. T.
66.50	.123	Grorudite	Grussletten, Norway	E. K., I, 199.—W. T.
61.83	.102 (62.2)	Porphyrite	Süpplingen, Magdeburg, Prussia.....	W. T.

SUBRANG 4. PANTELLEROSE.

(II. 4, 1, 4.)

71.35	0.116	Grorudite	Kallerud, Norway......................	E. K., I, 199.—W. T.
67.89	.116	Pantellerite	Pantellaria	Z. K., VIII, 186.—W. T.
67.48	.131	.....do	.....do	Do.
67.18	.122	.....do	.....do	Do.

RANG 2. DACASE.

SUBRANG 3. ADAMELLOSE.

(II. 4, 2, 3.)

66.57	0.103	Granite-porphyry	Kirche Wang, Silesia.................	Rosenbusch, El., 195.
63.97	.105	Quartz-mica-diorite ..	Crandall Basin, Wyo	Bull. 168, 94.—W. T.
62.51	.090	Syenite...............	Reichenstein, Silesia	N. J., 1890, I, 206.—W. T.
61.93	.104	Granitite	Laveline, Vosges	Rosenbusch, El., 78.
59.24	.095 (59.5)	Trachyte-andesite....	Highwood Mountains, Mont	Bull. 168, 131.—W. T.

SUBRANG 4. DACOSE.

(II. 4, 2, 4.)

65.50	0.107	Andesite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
64.47	.098	Granitite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
63.50	.101	Dacite................	Chiles, Colombia, South America	J. G., I, 171.—W. T.
61.56	.102	Andesite	Tower Creek, Yellowstone Park	Bull. 168, 108.—W. T.
56.59	.083	Quartz-diorite........	Sauk Center, Minn	R. T., 1879, XXXIV.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. TONALASE.

SUBRANG 3. HARZOSE.

(II. 4, 3, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
64.34	0.081	Granite	Butte, Mont	Bull. 168, 117.—W. T.
63.85	.080	Granodiorite	Grass Valley, Cal	Bull. 168, 194.—W. T.
63.06	.069 (63.2)	"Schliere" in granite.	Riesengebirge, Silesia	N. J., 1898, XII, 236.—W. T.
61.73	.088	Syenite	Hodritch, Hungary	R. T., 1869, LX.
61.64	.078	Quartz-monzonite	Red Rock Creek, Butte, Mont	Bull. 168, 118.—W. T.
60.68	.090 (60.7)	Andesite	Mount Pagos, Asia Minor	A. J. S. III, 1897, 43.—W. T.
60.17	.090	Latite	Tintic district, Utah	Bull. 168, 166.—W. T.
59.76	.094	Monzonite	do	Do.
57.80	.063	Quartz-pyroxene-diorite.	Sonora, Tuolumne County, Cal	Bull. 168, 204.—W. T.
57.69	.064 (58.1)	Mica-diorite	Gippsland, Victoria	E. K., II, 37.—W. T.
57.26	.076	Quartz-mica-diorite	Sierra County, Cal	Bull. 168, 192.—W. T.

SUBRANG 4. TONALOSE.

(II. 4, 3, 4.)

66.91	0.055	Tonalite	Adamello Stock, Tyrol	Rosenbusch, El., 140.—W. T.
65.83	.080	Granite	Granite Creek Station, Nev	Fortieth Par., I, 110.
65.39	.081	Dacite	Cumbal, Colombia, South America	J. G., I, 171.—W. T.
65.11	.083	Quartz-mica-diorite	Electric Peak, Yellowstone Park	Bull. 168, 88.—W. T.
64.81	.073	Porphyrite	Leadville district, Colo	Bull. 168, 155.—W. T.
64.12	.077 (.076)	Quartz-norite	Tyrol	Rosenbusch, El., 140.
64.07	.083	Quartz-mica-diorite	Electric Peak, Yellowstone Park	Bull. 168, 87.—W. T.
63.56	.084	Hornblende-dacite	Colombia, South America	J. G., I, 171.—W. T.
63.47	.075	Andesite	Suppans Mountain, Tehama County, Cal.	Bull. 168, 182.—W. T.
63.28	.077	do	Mount Hood, Oreg	Fortieth Par., I, 604.
63.16	.089	Trachyte	Henry Mountains, Utah	Bull. 168, 167.—W. T.
63.03	.070	Andesite	Mount Shasta, Cal	Bull. 168, 176.—W. T.
62.71	.084	Diorite	Gunnison County, Colo	Bull. 168, 159.—W. T.
62.65	.095	Hornblende-porphyrite.	Herman Peak, Colo	Bull. 168, 164.—W. T.
62.62	.070	Quartz-mica-diorite	Mariposa County, Cal	Bull. 168, 209.—W. T.
62.44	.071	Andesite	Shasta County, Cal	Bull. 168, 181.—W. T.
62.09	.070	Hornblende-porphyrite.	Nevada City, Cal	Bull. 168, 194.—W. T.
61.58	.074 (61.8)	Andesite	Mount Shasta, Cal	Bull. 168, 176.—W. T.
61.40	.048	Syenite	Riesengebirge, Silesia	N. J., 1898, XII, 234.—W. T.
61.22	.089 (61.4)	Mica-diorite	Electric Peak, Yellowstone Park	Bull. 168, 87.—W. T.
61.17	.077	Andesite	Shasta County, Cal	Bull. 168, 183.—W. T.
61.16	.093	Andesite-porphyry	Crandall Basin, Wyo	Bull. 168, 94.—W. T.
61.09	.070	Andesite	Colombia, South America	J. G., I, 171.—W. T.
61.04	.090	do	do	Do.
60.93	.073	do	Tuscan Buttes, Cal	Bull. 168, 181.—W. T.
60.30	.088 (60.4)	do	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.
60.20	.068	do	Pilot Peak, Plumas County, Cal	Bull. 168, 188.—W. T.
60.05	.079	do	Colombia, South America	J. G., I, 171.—W. T.
60.04	.078 (60.3)	do	Shasta County, Cal	Bull. 168, 181.—W. T.
60.02	.074 (59.8)	do	Sierra County, Cal	Bull. 168, 193.—W. T.

The following is a list of the canals, compiled from data recently obtained by the State engineer:

List of irrigation ditches along Niobrara River, in Nebraska, west of the one hundred and third meridian.

Name.	Location of intake.			Approximate length.
	Sec.	T.	R.	
Sioux County:				*Miles.*
Bigelow & Seymour ditch	19	31	57	1.75
Warneke's ditch	27	31	57	2.00
Johnson's ditch	36	31	57	.75
Lacota ditch	1	30	57	3.00
Peter Bourett's ditch	29	30	56	2.00
Earnest ditch	9	29	56	4.00
McGinley & Stover upper ditch	23	29	56	3.50
McGinley & Stover lower ditch	25	29	56	3.00
Harris & Neece ditch	3	28	55	10.00
La Belle ditch	6	28	54	2.00
——— ditch	4	28	54	4.00
Irion Brothers' ditch	1	28	54	2.00
Moore's ditch	9	28	53	3.50
Boxbutte County:				
McLaughlin ditch	9	28	52	3.00
Vincent ditch	10	28	52	1.00
Hughes ditch	1	28	52	2.00
Dawes County:				
Snow ditch	35	29	51	1.00
Palmer ditch	36	29	51	5.00
Furman ditch	29	29	50	3.00
Enterprise ditch	28	29	50	3.50
Hatch & Cross ditch	25	29	50	3.00
McMannis & Neeland ditch	29	29	49	2.00
Total	....	....	....	65.00

WHITE RIVER BASIN.

The relatively large volumes of running water in White River and those of its branches which head in the canyons on the north front of Pine Ridge have been utilized at various points for irrigation. Many ditches have been constructed, and there are plans for a more extensive use of the waters. At present about 3,655 acres are under irrigation, in greater part along the main valley.

The following list of ditches is compiled from data obtained by the State engineer during 1897:

List of irrigation ditches in White River Basin, in Nebraska, west of the one hundred and third meridian.

Name.	Location of intake.				Length.
		Sec.	T.	R.	Miles.
Sioux County:					
Lewis ditch	White River	27	31	55	0.50
Schwartz-Hughson ditch	do	26	31	55	.25
Tucker's ditch	do	34	31	54	.75
Colville ditch	Kyle Creek	3	30	54	1.00
Diedrichson ditch	White River	1	30	54	.50
Johnson ditch	do	7	30	53	.50
Jacobson ditch	do	32	31	53	.50
Mason ditch	do	32	31	53	.25
Crawford Citizens' ditch	do	23	31	53	1.50
					5.75
Dawes County:					
Crawford Citizens' ditch	do	23	31	53	18.50
Hazleton ditch	White Clay Creek.	13	31	52	1.00
Cooper ditch	do	2	31	52	1.75
Butterworth ditch	White River	3	31	52	.50
Hall's ditch	do	34	32	51	13.00
White River Irrigation Company's ditch.	do	34	32	52	2.00
McFarland's ditch	White Clay Creek.	35	32	52	.75
Harris & Cooper ditch	White River	25	32	52	10.00
Rasher ditch	do	19	32	51	1.00
Welling ditch	do	17	32	51	.50
Harris ditch	do	17	32	51	2.00
McManus ditch	Hooker Creek	7	31	51	1.00
Stewart Brothers' ditch	Little Cottonwood Creek.	8	32	52	1.50
Thomas Stewart ditch	do	8	32	52	.75
Spring Creek ditch	Spring Creek	13	32	52	.75
Spring Creek ditch No. 1	do	18	32	51	1.00
Kusil ditch	Little Cottonwood Creek.	9	32	51	1.00
Mace ditch	West Ash Creek.	2	31	51	1.00
West Ash Creek Irrigation Company's ditch.	do	36	32	51	2.00
Baron ditch	East Ash Creek.	32	32	50	.50
Ox Yoke ditch	do	31	32	50	1.50
James Wilson ditch	Indian Creek	10	31	50	.125
Seegrist ditch	do	3	31	50	.50

List of irrigation ditches in White River Basin, in Nebraska, etc.—Continued.

Name.	Location of intake.				Length.
		Sec.	*T.*	*R.*	*Miles.*
Dawes County—Continued.					
Flood ditch	East Fork of Indian Creek.	33	32	50	0.75
Smock's ditch	Trunk Butte Creek.	26	32	50	.50
Goff ditch	Dead Horse Creek.	9	31	49	1.00
Norton ditch	do	9	31	49	.75
Woodruff ditch	do	32	32	49	.75
Kemery Ram	do	32	32	49	.50
W. Wilson's ditch	Chadron Creek.	12	32	49	.50
H. M. Wilson's ditch	do	12	32	49	.75
Half Diamond	do	1	32	49	1.00
					69.125
Total					74.875

LODGEPOLE VALLEY.

The water of Lodgepole Creek has been utilized for irrigation for several years, and at times practically all the stream has been diverted into the fields. Hay has been the principal crop, but grains and vegetables have also been irrigated to some extent. The average volume of the creek is about 4 cubic feet per second, but along some portion of the valley the waters sink beneath the surface and, traveling underground for some distance, emerge again in springs. The following facts relating to this valley are taken from notes by Mr. Adna Dobson, made in the summer of 1895:[a]

Commencing from the west, the first ditch is the Hoover, which supplies water for about 50 acres; then come the ditches of S. A. Pierce and L. C. Kinney, which supply water for about 575 acres, mainly of hay lands. In the next 4 miles no more water is taken out, and then comes the head of the Young ditch, which supplies water for about 30 acres, extending to sec. 34, T. 15, R. 57. Five miles lower down is the ditch of Carl Ruttner, which takes water on each side of the creek, the total amount being 4.9 cubic feet a second, which is used for covering about 40 acres. One mile lower down is the beginning of J. J. Kinney's south ditch, which takes all the water in the creek, 3.6 cubic feet a second, for the cultivation of about 140 acres. One-half mile below this is the head of J. J. Kinney's north ditch, into which the entire creek is diverted. The amount of water is 2.1 cubic feet a second for the watering of 190 acres. These ditches are used alternately in order to obtain greater volume. The amount of water in the creek increases rapidly below the head of Mr. Kinney's ditch, and at the east line of sec. 34, one-half mile below, the creek is running about 6 cubic feet per second. Within the next 3 miles is the Hurley, Liley & Polly ditch, which takes 4.5 cubic feet of water a second for the irrigation of 160 acres. Two miles below this is the head of the Hurley & Polly ditch for the irrigation of about 125 acres. One-half mile lower down the valley is the head of the Bay State ditch, which takes 2.5 cubic feet of water a second for 100 acres. In the next 7 miles are the McIntosh, Circle Arrow, and Brady ditches, with only limited supplies of water, the creek becoming practically dry above Mr. Brady's head gate in sec. 28, T. 15, R. 54, and continuing so to a point in sec. 4, T. 14, R. 52, where it again appears. A measurement at the head of the Adams ditch, in sec. 31, T. 14, R. 52, showed 2¼ cubic feet a second, which is taken by the Adams ditch for the cultivation of 245 acres, mainly of hay. Next below is Thomas Gunderson's ditch, which has 5 cubic feet of water a second for 100 acres. In sec. 7, T. 14, R. 51, is the ditch of Mr. Hans Christianson, which takes about 1 cubic foot of water a second for 70 acres. One and one-half miles below this is the ditch of Mr. James Mitchell, which takes 3.5 cubic feet a second for 60 acres; and next below is the head of Mr. John Anderson's ditch, for 200 acres. This ditch is used alternately with the Mitchell ditch in order to have a sufficient volume of water. Then comes the very small ditch of Mr. J. A. Shanahan for the irrigation of 2 or 3 acres. The next dam below is for Mr. M. Urback's ditch. Then there is the ditch of N. P. Lingholm, which heads in the SE. ¼ sec. 14, T. 14, R. 51, and provides water for 30 acres. It was taking 1.5 cubic feet of water a second at the time of observation. The creek is dry below this through sec. 13 and nearly through sec. 19. Near the east line of sec. 19 the water rises again, and at the head of the Couch ditches, in the SW. ¼ sec. 20, T. 14, R. 50, 2 cubic feet a second is available for the irrigation of about 40 acres. Runge's ditches, Nos. 1 and 2, are in secs. 28 and 29, T. 14, R. 50, and provide for about 105 acres. The Ickes ditch comes next, but the amount of water is hardly sufficient to cover more than 100 acres. About one-half cubic foot of water a second passes the Ickes dam and fills a small pond at the head of the Adams & Tobin ditch, but the supply was inadequate to cover the 180 acres to be irrigated. Below this dam the creek is entirely dry for the next mile, where the water rises again in springs; and at the head of the Trognitz ditch, in sec. 36, T. 14, R. 50, one-half a cubic foot of water a second flows into the ditch and is used for the irrigation of about 34 acres. It is the same ditch that was built by the United States to supply water for Fort Sidney.

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[a] First Biennial Report of the State Board of Irrigation of the State of Nebraska for 1895 and 1896, prepared by W. R. Akers, Lincoln, 1897, pp. 151-157.

The table following gives the acreage of crops irrigated in the Lodgepole Valley west of the one hundred and third meridian in 1896, according to the first report of the State board of irrigation (p. 158).

Acreage of crops irrigated in the Lodgepole Valley west of the one hundred and third meridian in 1896.

	Acres.		Acres.
Alfalfa	317	Barley	20
Native hay	2,160	Rye	2
Corn	80	Potatoes	42
Oats	66	Garden trees, etc	25
Wheat	63	Total	2,832
Millet	57		

HAT CREEK BASIN.

The upper portions of Hat Creek and its numerous branches rising in canyons in the northern slopes of Pine Ridge contain water in sufficient supply for the irrigation of many local areas. These are mainly in the relatively narrow canyons, where only small strips of land are so situated as to be easily watered. The volume of water in most cases is ample and is derived from ever-flowing springs. Nearly all the canyons contain small, short canals, which serve for the irrigation of numerous small farms. The total area under irrigation in 1897 was estimated to be 1,860 acres.

The following is a list of the canals according to the plots of the State engineer:

List of irrigation ditches in Hat Creek Basin, Sioux County, Nebr.

Name.	Location of intake.				Length.
		Sec.	*T.*	*R.*	*Miles.*
Steel ditch	Hat Creek	16	32	55	1.50
Coffee's ditch	do	26	33	55	5.00
Miller ditch	do	23	33	55	.75
Holly's ditch	Boggy Creek	31	33	54	1.00
Old Sowbelly ditch	Sowbelly Creek	7	32	55	2.00
Hall's ditch	do	6	32	55	.50
M. D. Jordan's ditch	do	21	33	55	1.50
Schlitz ditch	Cedar Creek	35	33	56	2.00
Valdeg ditch	Prairie Dog Creek	3	32	56	.50
Zerbst ditch	do	25	33	56	1.00
Big Monroe Creek ditch	Big Monroe Creek	33	33	56	2.00
Biehle ditch		32	33	56	.75
Nolan's ditches, No. 1 and No. 2	Warbonnet Creek	23	33	57	1.25
Kay's ditch	do	26	33	57	.75
Daut ditch	do	30	33	56	1.00
——— ditch	do	31	33	56	1.00
Warbonnet ditch	do	21	33	56	1.50
Woodruff's ditch	Jim Creek	14	33	57	1.00
Slattery's ditch	do	13	33	57	1.00
Jim Creek ditch	do	8	33	56	.50
Hamlin ditch	Squaw Creek	10	33	57	.50
Dunn's ditch	do	11	33	57	2.00

List of irrigation ditches in Hat Creek Basin, Sioux County, Nebr.—Continued.

Name.	Location of intake.				Length.
		Sec.	*T.*	*R.*	*Miles.*
P. D. Dunn's ditch	do	3	33	57	1.00
Turner's ditch	Antelope Creek	26	34	57	1.50
Story's ditch	do	8	34	56	1.00
Cherry Creek ditch	Cherry Creek	29	33	54	.25
Total					32.75

WINDMILL IRRIGATION.

Several farmers in western Nebraska have experimented with windmill irrigation with encouraging results. There are large supplies of underground waters under the high table-lands, beginning with Pine Ridge and lying in broad expanse between the larger valleys. This is notably the case on the fine table lying between the valleys of Lodgepole Creek and Pumpkinseed Creek. These waters are usually at a depth of over 175 feet, but a large windmill soon raises sufficient water to fill a fair-sized reservoir. About 10 acres seems to be the limit for irrigation from one windmill, but this area will afford sufficient crops for local use. A reservoir is essential for satisfactory irrigation from a pump, but there usually is no difficulty in constructing one in the table-land areas.

CLIMATE.

Western Nebraska has a climate of typical plains character. It is dry and hot in summer, moderately moist in late spring, and cold, but with little snow, in winter. There is considerable variability in the climatic features from year to year, rather more than is found farther south or north, and some local variations from point to point, particularly in rainfall. Records of weather were kept for many years at Sidney, in the Lodgepole Valley, and at Fort Robinson, on White River, while for shorter periods observations have been made at Alliance, Gering, Hay Springs, Kimball, and Camp Sheridan. In Pl. XLII there is given a graphic reproduction of rainfall records covering a period of several years at some of the stations above mentioned, compiled from an article on the Rainfall of Nebraska,[a] by C. D. Swezey and G. A. Loveland, together with data for 1896 and 1897, kindly supplied by Mr. Loveland.

TIMBER.

The occurrence of timber in this region is restricted to certain localities of relatively limited extent. In the greater part of the plains area there is no timber at all, and the valleys of the Platte and upper Niobrara rivers and Lodgepole Creek do not contain trees. Along the northern escarpment of Pine Ridge, on the slopes of the White River and Hat Creek basins, there is a moderately wide zone of scattered

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[a] University of Nebraska, Bull. Agric. Exper. Stat., vol. 8, article 4, 1896.

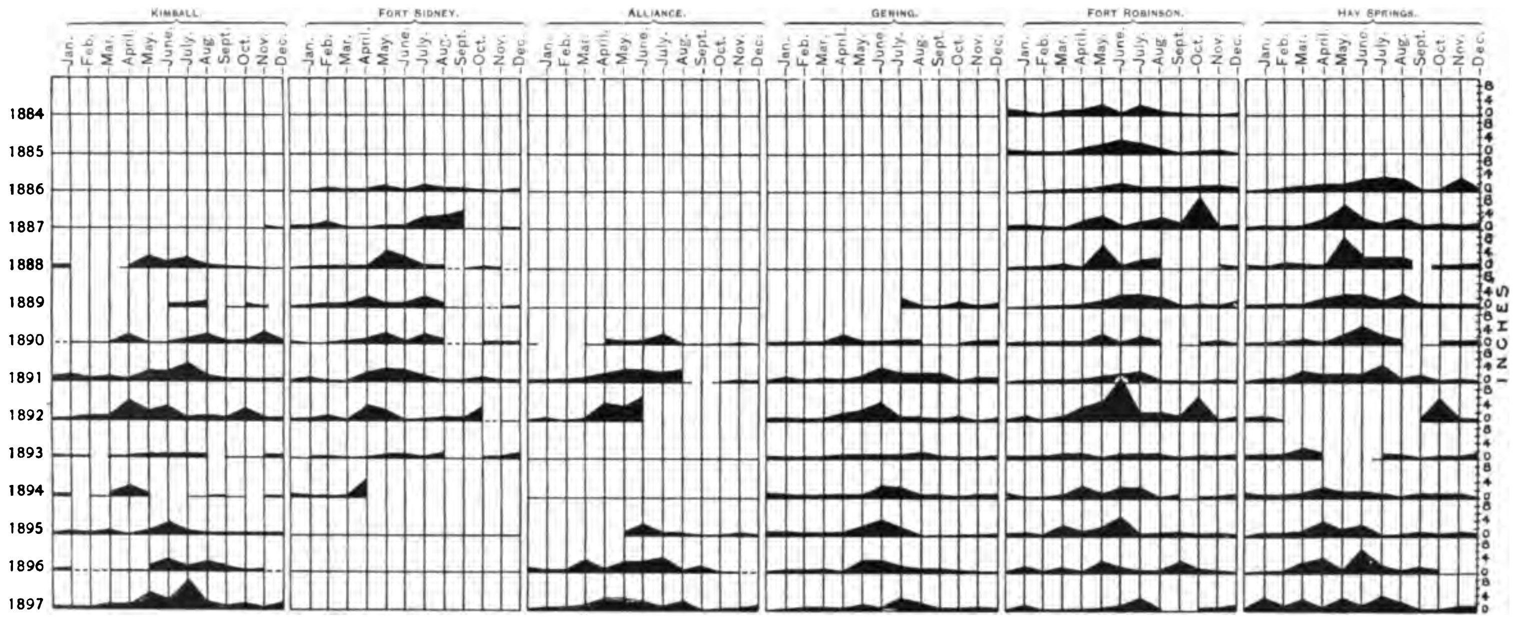

DIAGRAM OF RAINFALL AT LOCALITIES IN WESTERN NEBRASKA, 1884 TO 1897.

.... No precipitation. —— Trace. The absence of horizontal line indicates that no observations were recorded during a portion of the year.

pine forest. It extends from the crest of the ridge down nearly to the foot of the steeper slopes, and the aggregate amount of timber is fairly large. Along the ridge south of North Platte River there was formerly considerable pine, and many of the slopes north of Platte River and south of Pumpkinseed Valley maintained a scattered growth of pine. Some of the canyons in this region contain deciduous trees in small groves, and this is also the case in the many canyons in the northern slopes of Pine Ridge and at intervals along the banks of White River. The extent of the timber in this region is shown in Pl. XLIII. The principal tree is the Rocky Mountain pine (*Pinus ponderosa*). It attains a diameter of from 1 to 2 feet where the conditions are most favorable, but its growth is somewhat scattering, and deep inroads have been made on the supply by woodcutters. The young pines appear to be thrifty, as they spring up abundantly on most of the slopes, and are growing vigorously. Some features of the pine growth are shown in Pls. VIII and XXI.

In the region adjoining North Platte River the growth of pines is rather scanty, and nearly all of the larger trees have been or are being cut. This is also the case along the edge of the table-land south of Pumpkinseed Creek.

The deciduous trees of the region comprise mainly cottonwood (*Populus monilifera*), with a moderate proportion of box elder (*Negundium americanum*), and a small variety of other similar trees.

ELEVATIONS.

List of elevations in Nebraska west of the one hundred and third meridian.

WESTERN CHEYENNE COUNTY.

Locality.	Altitude.	Authority.
	Feet.	
Lapeer	3,638	U. S. G. S. bench mark.
Courthouse Rock	4,100	Do.
Jail Rock	4,002	Do.
Roundhouse Rock	4,255	Do.
Twin Mounds	4,309	Do.
Redington	3,870	Do.
Camp Clarke	3,705	Do.
Springs on Middle Creek	3,830	Do.
Chimney Rock	4,242	Do.
Bird Cage Gap	4,028	Do.
Bayard	3,780	Do.
Redington Gap	4,126	Do.
Cyrus	4,320	Do.
Spring Lakes	4,260	Do.
Duggers Springs	4,030	Do.
Ridge at head of McManigle Canyon	4,520	Do.
Table-land T. 22, R. 50 W	4,200-4,300	Do.

List of elevations in Nebraska west of the one hundred and third meridian—Continued.

WESTERN CHEYENNE COUNTY—Continued.

Locality.	Altitude.	Authority.
	Feet.	
Ickes post-office	4,415	Barometer.
Table at head of Wild Horse Canyon	4,450	U. S. G. S.
Sidney	4,090	Gannett.[a]
Margate siding	4,138	Union Pacific Railroad.
Bronson	4,203	Do.
Herdon siding	4,301	Do.
Potter	4,377	Gannett.[a]
Jacinto siding	4,486	Union Pacific Railroad.

KIMBALL COUNTY.

Dix	4,542	Union Pacific Railroad.
Owasco siding	4,616	Do.
Kimball	4,697	Do.
Adams	4,781	Do.
Bushnell siding	4,859	Do.
Smeed siding	4,925	Do.

BANNER COUNTY.

Wildcat Mountain	5,038	U. S. G. S.
Hogback Mountain	5,082	Do.
Castle Rock	4,472	Do.
Bighorn Mountain	4,718	Do.
Wrights Gap	4,425	Do.
Gabe Rock	5,006	Do.
Freeport	4,010	Do.
Harrisburg	4,500	Do.
Ashford	4,230	Do.
Mud Springs	4,640	Do.
Willow Springs	4,450	Do.
Funnel Rock	4,502	Do.
Gabe Springs	4,700	Do.
Long Springs	4,700	Do.
Summit of table south of Harrisburg	5,100	Barometer.
Smokestack Rock	4,326	U. S. G. S.
Sheep Mountain	4,507	Do.
Williams Gap	4,420	Do.
Hubbard Gap	4,494	Do.

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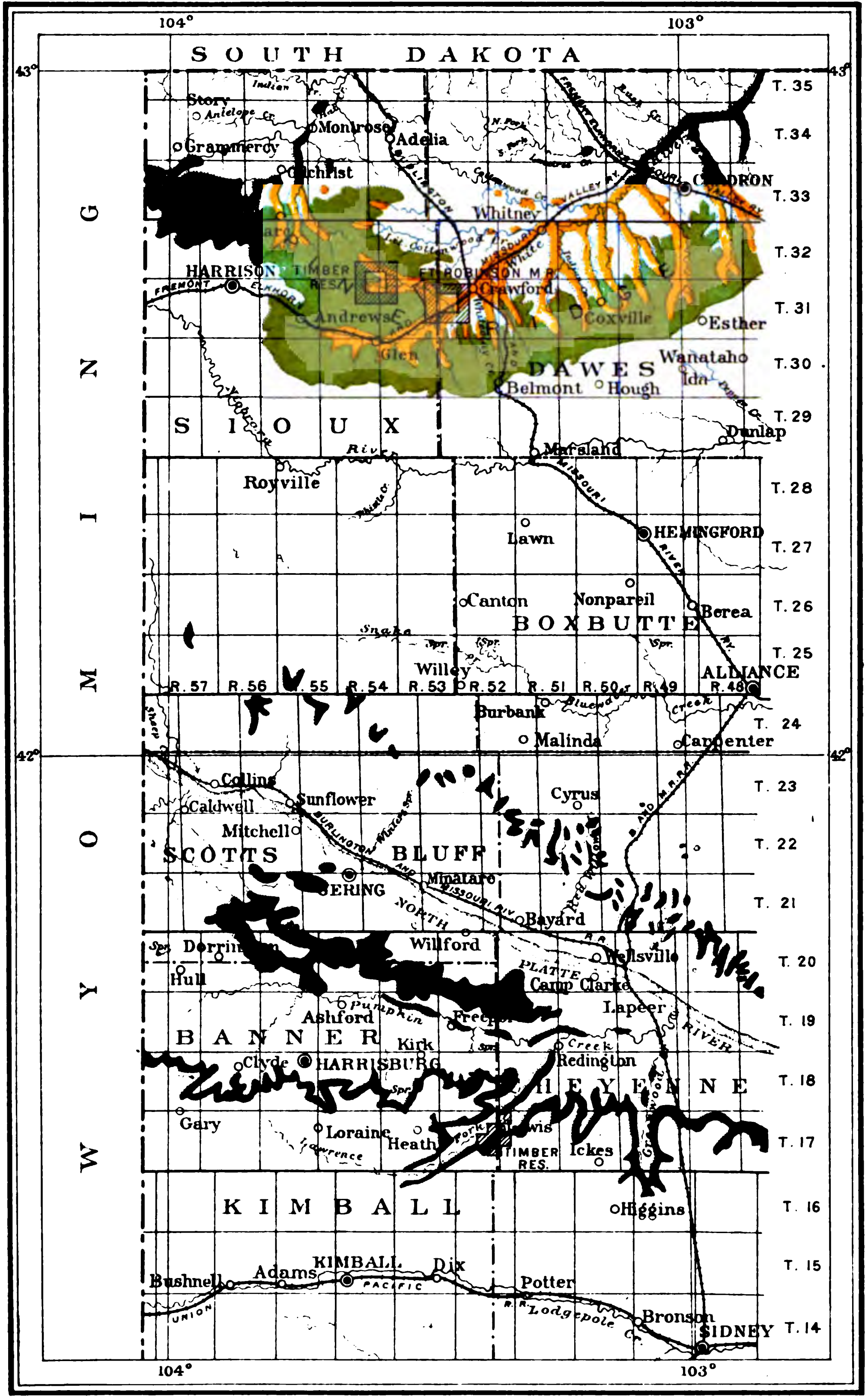
[a] Dictionary of altitude in the United States: Bull. U. S. Geol. Survey No. 160, 1899.



MAP SHOWING DISTRIBUTION OF TIMBER IN WESTERN NEBRASKA

BY N. H. DARTON

Scale of miles

10 5 0 10 20 30

■ PINE TIMBER ▨ COTTONWOOD, BOXELDER, AND OTHER DECIDUOUS TIMBER

JULIUS BIEN & CO. LITH. N.Y.

List of elevations in Nebraska west of the one hundred and third meridian—Continued.

SCOTTS BLUFF COUNTY.

Locality.	Altitude.	Authority.
	Feet.	
Scotts Bluff	4,662	U. S. G. S.
Dome Rock	4,560	Do.
Gering	3,902	Do.
Sedan	3,965	Do.
Winter Springs	3,990	Do.
Minatare	3,825	Do.
Sunflower	3,940	Do.
Collins	4,018	Do.
Caldwell	4,050	Do.
Mitchell	4,000	Do.
Larissa	3,960	Do.
Dorrington	4,450	Do.
Intake of Winter canal	3,900	Do.
Intake of Enterprise canal	3,980	Do.
Roubedeau Pass	4,480	Do.
Signal Butte	4,583	Do.
Summit of Ridge at head of Cedar Canyon.	4,860	Do.
Mitchell Pass	4,180	Do.
Bald Peak	4,420	Do.
North Platte River at Wyoming line	4,035	Do.
Castle Rock	4,473	Do.
Steamboat Rock	4,319	Do.
Roundtop Rock	4,479	Do.
Coyote Hill	4,460	Do.

SIOUX COUNTY.

Snyder's ranch	4,310	U. S. G. S.
Sturdivant's ranch	4,375	Do.
SW. corner of the county	4,050	Do.
NW. corner of the county	4,125	Barometer.
Harrison	4,849	F., E. and M. V. Rwy.
Andrews	4,422	Do.
Glen	4,038	Do.
Adelia	3,725	B. and M. R. R. R.
Mansfield	3,628	Do.
Niobrara River at Wyoming line	4,730	Barometer.
Niobrara River at eastern margin of the county.	4,200	Do.

List of elevations in Nebraska west of the one hundred and third meridian—Continued.

SIOUX COUNTY—Continued.

Locality.	Altitude.	Authority.
	Feet.	
Niobrara River at Royville	4,457	U. S. G. S.
Niobrara River at mouth of Whistle Creek.	4,280	Do.
Highest sandhill in sec. 17, T. 26, R. 55.	5,100	Do.
Highest sandhill in sec. 21, T. 27, R. 56.	5,020	Do.
Corbin's ranch	4,495	Do.
Mud Springs	4,470	Do.
Coyote Springs	4,520	Do.
McGinley Lakes	4,530	Do.
East Spring	4,525	Do.
Spottedtail Springs	4,120	Do.
Wind Springs	4,460	Do.
Gilchrist	3,900	Barometer.
Montrose	3,750	Do.
Roundtop	4,525	Do.
Coliseum Rock	5,050	Do.
Pine Ridge at Wyoming line, T. 33, R. 57.	5,060	Do.
Pine Ridge, south of Andrews	4,800	Do.
Pine Ridge, south of Glen	4,810	Do.

DAWES COUNTY.

Fort Robinson station	3,775	Gannett.[a]
Crawford	3,674	F., E. and M. V. Rwy.
Whitney	3,404	Do.
Dakota Junction	3,256	Do.
Remington	3,660	B. and M. R. R. R.
Rutland	4,141	Do.
Belmont	4,493	Do.
Marsland	4,156	Do.
Summit of Pine Ridge, near Belmont.	4,600	Barometer.
Niobrara River at 103d meridian	3,900	Do.

BOXBUTTE COUNTY.

Hemingford	4,256	B. and M. R. R. R.
Girard	4,365	Do.

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[a] Loc. cit.

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Classified list of analyses used in constructing diagrams—Continued.

SECTION 3. VENANZIASE.

Subrang 2. Venanzose.

(IV. 1, 5, 1, 3, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
41.43	0.152	Venanzite	San Venanzo, Umbria, Italy	A. W. B., 1899, VII, 113.—W. T.

ORDER 2. SCOTARE.

SECTION 1. ——.

Rang 1. ——.

SECTION 1. ——.

Subrang 2. ——.

(IV. 2, 1, 1, 1, 2.)

53.05	0.018	Augite-norite	Madras, India	W. T.

SECTION 3. BRANDBERGIASE.

Subrang 2. Brandbergose.

(IV. 2, 1, 1, 3, 2.)

45.05	0.030 (45.9)	Pyroxenite	Brandberg, Norway	Q. J. G. S., L, 31.—W. T.

Subrang 3. ——.

(IV. 2, 1, 1, 3, 3.)

45.04	0.209	Nephelite-basalt	Katzenbuckel, Odenwald, Baden	Rosenbusch, El., 357.

SECTION 2. PAOLIARE.

Rang 1. Paolase.

SECTION 2. ——.

Subrang 2. ——.

(IV. 2, 2, 1, 2, 2.)

47.41	0.031	Augite-peridotite	Peekskill, N. Y	A. J. S., XXXI, 1886, 40.—W. T.
42.68	.077	Hornblende-basalt	Hauk, S. Rhone	Rosenbusch, El., 309.
40.42	.038	Olivine-gabbro	Crazy Mountains, Mont	Bull. 168, 122.—W. T.
40.15	.000	Koswite	Koswinsky, Ural Mountains	O. N., 119.
39.59	.057	Nephelite-basalt	Ottendorf, Silesia	R. T., 1884, LXIV.

SECTION 3. PAOLIASE.

Subrang 2. Paolose.

(IV. 2, 2, 1, 3, 2.)

41.41	0.000 (41.6)	Koswite	Koswinsky, Ural Mountains	O. N., 119.
38.39	.031 (37.5)	Jacupirangite	Magnet Cove, Ark	J. G., IX, 620.—W. T.
38.38	.022	.....do	Sao Paulo, Brazil	Do.
36.51	.075	Elecolite-mica-syenite.	Magnet Cove, Ark	Do.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

CHEMICAL COMPOSITION OF IGNEOUS ROCKS

EXPRESSED BY MEANS OF DIAGRAMS

WITH REFERENCE TO ROCK CLASSIFICATION ON A QUANTITATIVE CHEMICO-MINERALOGICAL BASIS

BY

JOSEPH PAXSON IDDINGS

WASHINGTON
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1903

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Washington, D. C., May 26, 1903.

Sir: I have the honor to transmit herewith a manuscript by Joseph Paxson Iddings entitled "Chemical composition of igneous rocks expressed by means of diagrams, with reference to rock classification on a quantitative chemico-mineralogical basis," and to recommend that it be published as a Professional Paper.

The significance of a large number of chemical analyses of igneous rocks, with their many variable elements, each having a great range, is somewhat difficult of comprehension to all geologists and petrographers who have not devoted much time to their study. Mr. Iddings presents a method of expressing the most significant factors in each analysis by a simple diagram, and by grouping these individual diagrams on a certain principle he has succeeded in representing the great variation in composition and the chemical relationships of almost the entire range of igneous rocks in a way that is comprehensible at a glance. The facts thus brought out are discussed by him in their bearing on petrographic system. As a successful attempt at the elucidation of a complex problem the paper is of importance to all students of igneous rocks.

Very respectfully,

Whitman Cross,
Geologist in Charge, Section of Petrology.

Hon. Charles D. Walcott,
Director United States Geological Survey.

CHEMICAL COMPOSITION OF IGNEOUS ROCKS EXPRESSED BY MEANS OF DIAGRAMS, WITH REFERENCE TO ROCK CLASSIFICATION ON A QUANTITATIVE CHEMICO-MINERALOGICAL BASIS.

By Joseph Paxson Iddings.

INTRODUCTION.

The value of graphical methods for expressing relative quantities has been well established in all kinds of statistical exposition and discussion. Their use in conveying definite conceptions of relative quantities of chemical and mineral components of rocks is becoming more and more frequent, and the value of the results in some cases can not be overestimated. This is especially true when a series or group of rocks is being considered. The intricate variations in the amounts of numerous mineral components, or of chemical components, baffle most attempts to comprehend their interrelationships by simple contemplation or by study of the numbers in which they may be expressed. Many facts and relations are overlooked which are readily observed when diagrams are used to represent numerical figures. Moreover, visual memory is sufficiently developed in most persons to enable them to carry in mind simple geometrical forms, where it does not permit them to recollect manifold assemblages of oft-repeated numbers. Mental impressions of simple diagrams are, therefore, more definite and lasting and enable the student to store up a much greater amount of quantitative data than he could otherwise acquire.

Evidence of the appreciation of this fact by petrographers is found in the increasing use of diagrams in petrographical literature, and a brief sketch of the growth and elaboration of graphical methods for presenting quantitative petrographical data will serve as an appropriate introduction to the subject in hand. From this notice will be excluded those diagrams which serve to connect the names of rocks in series after the manner of expressing genealogical relationships, in which diagrams the space relationships are not strictly quantitative. Such diagrams have been used by George H. Williams, H. O. Lang, and other petrographers.

HISTORICAL REVIEW.

Among the earliest diagrams employed to represent relative quantities of rock constituents are those used by Reyer in 1877.[a] They are more or less generalized expressions, in one instance of the varying proportions of the chief oxide components in rocks and meteorites; in another of the varying amounts of the commoner rock-making minerals capable of being developed in rock magmas with different silica content. The diagrams used are rectangles subdivided by curved lines corresponding to the variations mentioned. Other diagrams express the variations of different kinds of rocks with respect to silica; the relation between specific gravity, silica percentage, and texture of mineralogically similar rocks; and the relative abundance of rocks of different compositions and textures.

Subsequently in his work, Theoretische Geologie,[b] he reproduces two of these diagrams and introduces others showing the proportions of chemical components in two series of minerals (feldspars and pyroxenes) and others showing the proportions of the chief minerals in three kinds of rocks. One diagram consists of adjacent, long, narrow rectangles, each divided into rectangular parts proportionate to the percentages of the oxide constituents in certain kinds of rocks, from granite to gabbro, and in five types of meteorites.

Judd,[c] in his book on Volcanoes, in 1881, makes use of a diagram to represent the varying amounts of chemical elements in rocks and meteorites. It is similar in form to one used by Reyer, already described.

In 1890 the author[d] constructed diagrams to exhibit the variation in chemical composition of rocks forming geologically related groups or series. In these diagrams the quantitative data represent specific analyses of different rocks in each series. The oxide constituents of each rock are referred to rectangular coordinates, the silica being plotted as abscissas, and the other oxides—alumina, ferric and ferrous iron, magnesia, lime, soda, and potash—being plotted as ordinates. Straight lines connecting successive loci of any one oxide, as those of alumina, indicate the variations in the amount of each constituent in the rock series. This is the chief feature brought out by these diagrams, the range and character of the variations being shown.

Similar diagrams have been used by Dakyns and Teall[e] to illustrate the chemical variations in the plutonic rocks of Garabal Hills and Meall Braec.

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[a] Reyer, E., Beitrag zur Fysik der Eruptionen. Vienna, 1877.

[b] Reyer, E., Theoretische Geologie. Stuttgart, 1888.

[c] Judd, J. W., Volcanoes. New York, 1881, p. 322, fig. 88.

[d] Iddings, J. P., The mineral composition and geological occurrence of certain igneous rocks in the Yellowstone National Park: Bull. Philos. Soc. Washington, vol. 11, January, 1890, pp. 207 and 211; also in Twelfth Ann. Rept. U. S. Geol. Survey, 1892, pp. 629 and 649; Mon. U. S. Geol. Survey, vol. 32, pt. 2, pp. 119 and 136; Origin of igneous rocks, Bull. Philos. Soc. Washington, vol. 12, June, 1892, and in Jour. Geol., vol. 1, 1893, p. 173.

[e] Dakyns, J. R., and Teall, J. J. H., Quart. Jour. Geol. Soc. London, vol. 48, 1892, p. 116.

Scotland; by Washington to express the chemical variation in the volcanic rocks of Ægina and Methana, Grecian Archipelago,[a] and in the rocks of Magnet Cove, Arkansas;[b] and by Cross[c] to show the chemical composition of the rocks of the Rosita Volcano, Colorado.

Harker[d] has employed the same form of diagram, but has used atomic ratios of the chemical elements instead of the oxides, to show the variations in the rocks of Carrock Fell, England. Subsequently he modified it slightly by using percentages of the oxide components instead of their molecular proportions to discuss the possibility of distinguishing igneous rock series from mixed igneous rocks.[e]

Loewinson-Lessing[f] has also made use of this method of exhibiting the variability of chemical composition in eruptive rocks, illustrating the great divergence in the composition of rocks classed under one name in the qualitative system and also the differences in composition of average magmas.

In 1900 Pirsson[g] pointed out the possibility of relating the variations in the chemical composition of rocks of one geological body to their position in that body by introducing their space relations into this form of diagram. He accomplished it by letting the abscissas represent distances in the rock body between the various rocks analyzed. By this modification of the diagram just described, he showed that the variations in chemical composition in such cases follow very regular laws, and with one or two elements determined in a variety of the rock the remainder may be found by means of the diagram.

Similar diagrams have since been used by Washington in discussing the differentiation in the rocks of Magnet Cove.[h]

Pirsson has also used a somewhat similar diagram to represent the variations in mineral composition of rocks of Yogo Peak, Little Belt Mountains, Montana.[i]

In 1896 Becke[j] represented the chemical composition of igneous rocks by diagrams of two kinds, constructed in a manner different from that of those just described. The first is a modification of a three-coordinate diagram for three variables, whose sum is a constant, based upon an equilateral triangle. The three factors chosen are Ca, Na, K. The zero point of the coordinate axis is the center of the triangle. From this point three axes run to the corners of the triangle, one for each of the elements, Ca, Na, K. The spot within the triangle determined by the values of Ca, Na, K, in a given rock analysis is the locus of the analysis (*Analysenort*). The various positions of these spots indicate the relative amounts of the elements named in the rocks compared. The other chemical elements in the rocks are represented on a second diagram supposed to stand at right angles to the plane of the first. It is drawn with rectangular coordinates, the abcissas being proportional to the ratio $\frac{Ca}{Ca + Na + K}$, and the ordinates representing the values of Si, Al, Fe, Mg. Each of these elements is located by a spot in the diagram.

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[a] Washington, H. S., Jour. Geol., vol. 3, 1895, p. 160.

[b] Washington, H. S., Bull. Geol. Soc. America, vol. 11, 1900, p. 404.

[c] Cross, W., Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 324.

[d] Harker, A., Quart. Jour. Geol. Soc. London, vol. 51, 1895, p. 146.

[e] Harker, A., Jour. Geol., vol. 8, 1900, pp. 389–399.

[f] Loewinson-Lessing, F., Compte rendu Congrès Géol. International, Seventh session, St. Petersbourg, 1899, Pls. I, II, and III.

[g] Pirsson, L. V., Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 569 et seq.

[h] Washington, H. S., Bull. Geol. Soc. America, vol. 11, 1900, p. 651.

[i] Op. cit., p. 568.

[j] Becke, F., Min. Pet. Mitth., vol. 16, 1897, p. 315–320.

In January, 1897, Michel Lévy[a] devised diagrams to exhibit certain chemico-mineralogical characters of igneous rocks, a single diagram representing an individual rock. The component oxides are first distributed into two groups, those that may combine with Al_2O_3 to form feldspars and those that may not. All the Al_2O_3 is set aside for feldspars, and to it is allotted K_2O, Na_2O, and sufficient CaO to satisfy it. An excess of CaO is placed with iron and magnesia. Silica may be introduced into the diagram or omitted, and in a subsequent publication[b] in the same year is expressed only in numbers stating the percentage. Rectangular coordinates are used and the values of the components are laid off on two axes intersecting at the zero point. Below this point is plotted the percentage of potash, and also that of iron oxide. To the right of the zero point is plotted the percentage of soda which may combine with alumina. In this direction, also, may be plotted the percentage of silica. Above the zero point is plotted the lime which may combine with alumina, and also the percentage of magnesia. If there is more lime than will satisfy the alumina remaining after potash and soda have been satisfied, this lime is plotted to the left of the zero point. Triangles are constructed by connecting the end of the potash line with that of the soda line, and the soda with feldspathic lime. Magnesia is connected with nonfeldspathic lime, and this with iron. Two triangles to the right of the *y* axis give an indication of the feldspathic constituents of the rock. The other two triangles to the left of the *y* axis represent the nonaluminous constituents. Modifications of the diagrams enter when there is an excess of alumina over alkalies and lime, and again when alumina is less than the alkalies.

Michel Lévy in the publication last cited also employs diagrams showing curves of variation for the percentages of the chemical components when subdivided in the manner just described.

These triangular diagrams have been used by Lacroix in describing the basic rocks accompanying the lherzolites and ophites of the Pyrenees,[c] and also in his work on the alkaline rocks of the petrographical province of Ampasindava, Madagascar.[a]

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[a] Lévy, A. Michel, Bull. Serv. Carte géol. France, vol. 9, No. 57, 1897, p. 38 and Pls. VII, VIII.

[b] Lévy, A. Michel, Bull. Soc. géol. France, 3d series, vol. 25, 1897, Pls. X to XV.

[c] Lacroix, A., Compte rendu Congrès Géol. International, Eighth session, Paris, 1901, Part II, pp. 834, 835.

In May, 1897, Brögger[b] presented a modification of the individual diagrams devised by Michel Lévy. This was done in illustrating the chemical composition of the group of rocks associated with the laurdalite of the Christiania region. Brögger's diagrams are composed of four coordinates in a plane intersecting in a common zero point. One is horizontal, another vertical, and the other two inclined, one 60° to the right, the other 60° to the left of the vertical axis. On these axes are plotted the molecular proportions of the chief oxide components of a rock. On the upper vertical axis are plotted the molecules of CaO, on the lower vertical axis the Al_2O_3. On the horizontal axis right and left is plotted the SiO_2, half and half. On the upper right inclined axis is plotted MgO; on the upper left one, the $FeO + Fe_2O_3$, indicated separately. On the lower right inclined axis is plotted K_2O, and on the lower left one Na_2O. The extremities of adjacent axes are connected by lines. These diagrams show at a glance the relative proportions of the molecules of the oxide constituents of each rock. The amount of CaO capable of being combined with Al_2O_3, not combined with K_2O and Na_2O, can be readily found by measuring the lengths of the several axes. The introduction of the silica and alumina adds to the instructiveness of this form of diagram.

Diagrams of this type have been employed by Hobbs[c] to express the average composition of groups of rocks classed together under various divisions of the qualitative system in general use at the present time. In these diagrams the inclined axes stand at 45° to the vertical axis.

Hackman[d] has made use of both the Becke and the Brögger diagrams to express chemical relations among the rocks associated with ijolite in Kuusamo, Finland.

Rosenbusch[e] uses narrow rectangular diagrams to express the relative proportions of the chemical elements (*Metallatome*) in two series of 26 rocks; one, a foyaite-theralite series, the other a granitodiorite and gabbro-peridotite series.

In February, 1898, the author[f] in an essay on rock classification, and later in another essay, made use of diagrams exhibiting the variations of rock analyses with reference to percentage of silica and alkali-silica ratio. These are constructed by using the silica percentages as abscissas, the zero point being to the right of the diagram, and 100 to the left. The ordinates represent the ratios obtained by dividing the sum of the molecular proportions of the alkalies, K_2O and Na_2O, by that of silica. The locus of each analysis is indicated by a round spot or by figures of other shapes.

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[a] Lacroix, A., Nouv. Arch. Museum Hist. Nat., 4th series, I, Paris, 1902, p. 180 et seq.

[b] Brögger, W. C., Die Eruptivgesteine des Kristianiagebietes. III. Videnskabsselskabets Schrifter. I. Math.-Naturv. Kl. 1897. No. 6. Christiania, 1898.

[c] Hobbs, W. H., Jour. Geol., vol. 8, 1900, pp. 1-31.

[d] Hackman, V., Bull. Com. Geol. Finlande, vol. 11, Helsingfors, 1900.

[e] Rosenbusch, H., Elemente der Gesteinslehre. Stuttgart, 1898.

[f] Iddings, J. P., Jour. Geol., vol. 6, 1898, pp. 92-111, 219-237.

In the same year, 1898, Michel Lévy[a] presented a new mode of coordination of diagrams to represent rock magmas, based in a measure on those just published by the author, to some features of which Michel Lévy took exception. These diagrams by Michel Lévy give the loci of rock analyses referred to two coordinates in the plane of drawing, and also to a third axis projected on the same plane. The abscissas (x) represent the silica percentages in the "white components" (elements blancs) of the rocks compared. The ordinates (y) represent the sum of the percentages of K_2O, Na_2O, and the CaO which may enter feldspar combined with Al_2O_3. The third coordinates (z) represent the percentages of MgO, FeO, Fe_2O_3, CaO, and SiO_2 in the ferromagnesian components of the rocks. The loci of the analyses are fixed by the rectangular coordinates x and y. Their relation to the axis z is indicated by their position with reference to diagonal lines representing the projected traces of certain planes with an inclined plane through z.

The usefulness of this diagram, which appears when the compositions of restricted groups of rocks are illustrated, is seriously impaired by repeated overlapping when many kinds of rocks are taken into account. The method undertakes to distribute the analyses with respect to the relative abundance of the white (leucocratic) components—quartz and feldspathic minerals—and the dark (melanocratic) ferromagnesian components in the first instance, and also with respect to the silica content of the leucocratic components.

It is clear that rocks containing various amounts of nephelite, leucite, and anorthite molecules with closely similar percentages of silica will be mingled together in the same part of the diagram, and that rocks with preponderant ferromagnesian minerals, since they are plotted wholly on a basis of characters belonging to the subordinate feldspathic minerals, will be indiscriminately mingled in one portion of the diagram.

In 1899 Loewinson-Lessing,[b] in his studies of eruptive rocks, an abstract of which was presented, without diagrams, to the International Geological Congress at St. Petersburg in 1897, makes use of two forms of diagrams, one after the method of the author, already alluded to, and another based on the method of relative rectangular areas used by Reyer. The diagram represents the various molecular proportions of the chemical components of a rock, or may represent the average of a group of rocks. It is a rectangular area divided by horizontal lines into spaces whose vertical dimensions correspond to the proportions of SiO, R_2O_3, RO, and R_2O in each case. These rectangles are subdivided by vertical lines into spaces whose horizontal dimensions correspond to the proportions of Al_2O_3 and Fe_2O_3 in R_2O_3, of FeO, CaO, and MgO in RO, and of K_2O and Na_2O in R_2O.

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[a] Lévy, A. Michel, Bull. Soc. géol. France, 3d series, vol. 26, 1898, Pls. III to VI.

[b] Loc. cit.

In 1900 Mügge[a] devised a form of diagram to express the proportions of the chemical components of rocks, based upon some features of Michel Lévy's and Brögger's diagrams. Several modifications of the diagram were suggested by Mügge. It will be sufficient to describe the form used by him to illustrate the composition of a number of selected rocks. The relative quantities of the oxide components, expressed molecularly, are plotted on four coordinate axes in one plane intersecting in a zero point and making equal angles with one another. One is vertical, one horizontal, and two inclined at 45°. The silica is represented by an octagonal area, constructed by plotting one-eighth of the total silica plus and minus on each axis. The other components are plotted outside this area on particular axes by adding their values to the silica already plotted. K_2O is plotted on the upper left inclined axis, Na_2O on the upper right one, MgO on the lower left inclined axis, CaO on the lower right one. FeO is plotted on the lower vertical axis, followed by Fe_2O_3 in the same direction. Al_2O_3 is divided into three parts, when sufficient, the first, equal molecularly to K_2O, is plotted to the left on the horizontal axis. A second, equal to the Na_2O is plotted upward on the vertical axis, and the remainder of the Al_2O_3 is plotted to the right on the horizontal axis. When there is less Al_2O_3 than $K_2O + Na_2O$, enough Fe_2O_3 is added to Al_2O_3 upward on the vertical axis to equal Na_2O. In this manner the relative amounts of potash-alumina molecules, soda-alumina molecules, and lime-alumina molecules are indicated.

In 1900 and 1901 Osann[b] made use of several types of diagrams to illustrate chemical characteristics of igneous rocks in his essay on a chemical classification of igneous rocks.

One is a triangular diagram somewhat similar to that used by Becke, exhibiting the distribution of analyses with respect to three coordinate axes making equal angles with one another. The three chemical factors of rocks employed in their comparison are chemico-mineralogical to some extent. One factor (A) consists of the sum of the percentages of K_2O and Na_2O which may be combined with Al_2O_3 in equal molecular amount. A second factor (C) represents the percentage of CaO which may be combined with Al_2O_3 in equal molecular amount. The third factor (F) represents the sum of the percentages of the remaining CaO,

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[a] Mügge, O., Neues Jahrb. Min., Geol. und Pal., 1900, vol. 1, pp. 100-112, Pls. V-VII.

[b] Osann, A., Min. Pet. Mitth., vol. 19, 1900, Pls. IV-VIII, XXV; vol. 20, 1901, Pls. VIII-XIV.

MgO, FeO. The sum of these is assumed to be a constant, and their relative proportions are determined on a basis of 20 units. With these three variables the position of a rock analysis within the equilateral triangle is located.

A second form of diagram expresses the variation in silica and alkalinity in certain rocks by means of lines connecting loci of analyses referred to two rectangular coordinates, the abscissas corresponding to the alkalinity, and the ordinates to the silica percentage. Another diagram of the same type exhibits the variability of different kinds of rock with respect to the relative proportions of soda and potash.

A third form of diagram is composed of narrow rectangles, whose lengths correspond to the range of variation in silica ratios for different kinds of rocks. The rectangles are placed by the side of one another, with their longer diameters adjusted to one ordinate representing values of silica ratios.

In 1902 Reid[a] used an equilateral triangle whose sides are divided into 100 parts, as a basis on which to plot the oxide components of igneous rocks.

PURPOSE OF THE DIAGRAMS.

A study of the various diagrams that have been employed by petrographers shows that their value depends upon the readiness with which their significance may be grasped and the use that is made of them. The first condition varies directly as the simplicity of the method of construction, both as to geometrical form and as to the factors on which they are based. The simpler the form of the diagram and the more characteristic its shape, the more definite the visual impression and the stronger the hold on the mind. It is also self-evident that the simpler the factors entering into it the better. The quantitative values of single rock components are simpler conceptions than intricate ratios and functions involving several different rock components. Moreover, a diagram is comparatively worthless unless it can be made to convey some definite impression not otherwise obtainable, or obtainable only with difficulty. Its employment should have some specific object. It is hoped that the diagrams presented in this paper will justify themselves and will produce certain definite impressions on the minds of petrographers who may study them.

The author's first purpose in constructing the accompanying diagrams is to express in the simplest graphical manner the chief chemical composition of all kinds of igneous rocks in a form that will permit the student to compare them at a glance and obtain a comprehensive view of the whole range of differences.

The diagrams are intended to exhibit the manifold character of the variations of the chemical components of rocks, and their extent. They are to show the gradual character of the variations; the transitions from rocks of one composition to those of another; and the distribution of the rocks throughout the range of their variations.

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[a] Reid, J. A., Bull. Dept. Geol. Univ. California, vol. 3, 1902, p. 18.

They are to demonstrate the absence of clusters of analyses in definite parts of the whole system and the absence of "natural" subdivisions of rocks on a basis of chemical composition.

They are to show the possibility of continuous series of rocks with diverse compositions, and to illustrate the chemical identity of rocks belonging to different genetic families.

Finally the diagrams exhibit the character of the quantitative classification of igneous rocks proposed by Cross, Iddings, Pirsson, and Washington, the range of composition of the five classes, as well as of the orders, rangs, and subrangs.

CONSTRUCTION OF THE DIAGRAMS.

As will be seen by looking at the plates, the diagrams are combinations of two kinds already in use. They consist of assemblages of individual rock diagrams, which are modifications of those devised by Michel Lévy and Brögger, the individual diagrams being arranged in a multiple diagram previously used by the author. The first are used to exhibit the chief chemical components of each rock taken into consideration; the second, to arrange these in an orderly manner for comparison with one another.

The small, individual diagrams are modified forms of those by Brögger. They are planned to exhibit the relative amounts of the chief oxide components of igneous rocks, namely: SiO_2, Al_2O_3, Fe_2O_3+FeO, MgO, CaO, Na_2O, K_2O, and also TiO_2. Other components are usually so slight that they are negligible in diagrams of such small scale. Owing to the fact that the small diagrams are arranged in the large diagram according to the silica, it is not necessary for the purposes of this paper to introduce SiO_2 into the construction of the individual diagram. The relative amount of SiO_2 is expressed by the position of the small diagram in the large one. This simplifies the small diagram.

The chemical components of rocks may be compared with one another as oxides of metals or as metals. As oxides, the form in which they are expressed in chemical analyses of rocks, they may be compared by means of percentage weights or of molecular proportions. As metals they would be compared by molecular or atomic proportions.

The use of oxides instead of metal elements is the more convenient method of comparison. It bears a more obvious and direct relation to the rock analysis and requires less effort to apply. It is as valuable in the discussion of chemico-mineralogical relationships as the use of metal elements. It has, therefore, been adopted in constructing these diagrams.

The value of basing the comparisons upon molecular proportions instead of percentage weights rests upon the fact that the chemical equivalency of the components is molecular or atomic, and that in this form they may be readily converted into mineral molecules for purposes of discussion and rock classification.

For purposes of comparison in diagrams of this type it is not necessary to reduce the original analysis to a sum of exactly 100. So far as the small individual diagrams are concerned the amount of change produced in the lengths of the lines would not be appreciable. Further, all elementary lines in one diagram would be affected in like proportion and the shape of the figure would remain unchanged, even could the alteration in the length of the lines be made visible. It would affect to a variable degree the position of the small diagrams within the large one in the direction of the silica abscissa, which will be discussed later.

The small, individual diagrams are constructed to exhibit the molecular proportions of the component oxides: Al_2O_3, Fe_2O_3+FeO, MgO, CaO, Na_2O, K_2O, and TiO_2. These are derived directly from the rock analysis by dividing the percentage weight of each oxide by its molecular weight. There is no further reduction. They are used in the proportions in which they are found in the rock, the assumption being that equal weights of different rocks are being compared.

Following Brögger's method, the several values of these oxides are plotted on coordinate axes in one place, intersecting at a common zero point. But the arrangement is different. For convenience in drawing on square-ruled paper the axes chosen are vertical, horizontal, and two at 45° to these. The simple, approximate relation between the sides and hypothenuse of a 45° triangle, namely, that when the hypothenuse is 10 units the sides are 7 units each (more exactly 7.071) allows the values to be readily plotted by assuming the diagonal of each square of the ruled paper to be 5 and the side $3\frac{1}{2}$. With larger diagrams and more exact requirements more accurate methods of plotting may be employed.

Since the small diagrams are to be compared by means of the multiple one, the position of the Brögger diagrams is inverted to conform more closely to the manner of constructing the large diagram. In the multiple diagram the more alkalic, and consequently more alkali-feldspathic, members of the series of rocks compared occur in the upper part; the less alkalic, and more ferromagnesian, in the lower part. So the alumina and alkalies are placed in the upper part of the individual diagrams, the iron and magnesia in the lower. The mode of construction is as follows: Al_2O_3 is plotted upward on the vertical axis; K_2O upward to the left on one inclined axis; Na_2O upward to the right on the other inclined axis; CaO is plotted downward on the vertical axis; MgO downward to the right; $FeO+2Fe_2O_3$ downward to the left; and TiO_2, when present in appreciable amount, is plotted to the left on the horizontal axis. The end of the Al_2O_3 ordinate is connected by lines with the ends of the K_2O and Na_2O ordinates, producing two triangles having a common side—the Al_2O_3 ordinate—and one angle the same in each—45°. Consequently the areas of the two triangles are proportional to the lengths of the K_2O and Na_2O ordinates. The relative impressions produced by these two triangles, colored green and yellow in the diagrams, are quantitatively the same as the relations between the molecular proportions of K_2O and Na_2O in the rock.

The end of the CaO ordinate is connected with the ends of the MgO and $FeO+2Fe_2O_3$ ordinate, making two triangles, colored blue and red in the diagrams, whose areas bear the same proportion to one another as the ratio between the molecules of MgO and the iron converted to FeO.

When TiO_2 is represented, the end of its ordinate is connected with that of the FeO ordinate.

The FeO and Fe_2O_3 are combined chiefly for simplicity, and the Fe_2O_3 is reduced to FeO because there is then a more uniform basis of comparison and a means of avoiding the analytical defects or errors in the determination of the two oxides of iron. The combination prevents a proper conception of the possibilities of mineral molecular combination so far as the iron is concerned, but this is beyond the adaptability of the diagrams in a strict sense.

It is evident that diagrams constructed on the molecular proportions of the oxide components of rocks may be easily converted into others, based on the proportions of the metal elements, by doubling the lengths of the three upper ordinates, Al_2O_3, K_2O, Na_2O. The upper half of each diagram would be double its former size, while the angular shape of the whole would remain the same.

The multiple diagram, by which the small individual ones are arranged for comparison and study, is constructed in the manner already described in the article on rock classification previously cited. It is intended to exhibit the distribution or variation of igneous rock analyses with respect to the silica and alkalies. The reasons for choosing these two factors are: First, the important rôle played by silica, the most abundant chemical component, and that which is dominant in the development of quartz, orthoclase, albite, leucite, or nephelite, orthorhombic pyroxene or olivine; second, the equally important rôle played by the alkalies in conditioning the character of the feldspathic mineral components of rocks, which are the preponderant ones in the great majority of cases; third, the fact that the other chemical components—lime, magnesia, and iron oxide—sustain to a considerable extent a reciprocal relation to those just mentioned. The greater the silica the less the content in lime, magnesia, and iron oxide. The same is true in general for the alkalies and these oxides.

One of the chief purposes of the diagram is to distribute the rocks in an orderly manner, so that unlike rocks shall be separated from one another as widely as possible and gradations between the extremes shall be made evident.

The silica is made the abscissa because it is the greater component and has the widest range. It is plotted in percentages instead of molecular proportions because the process is simpler, and as it is not brought into immediate quantitative relations to the linear elements of the individual diagrams there is no occasion for its quantitative linear comparison with them. Moreover, the large diagram could not be constructed on the same scale of units as the individual diagrams. It is therefore simpler and more convenient to use the percentage of silica given in the analyses.

The vertical ordinates represent the ratio between the sum of the molecular proportions of the alkalies ($K_2O + Na_2O$) and of the silica—$\frac{(K_2O + Na_2O)}{SiO_2}$. This ratio was selected because of the relation between the development of the alkali-feldspathic minerals in highly feldspathic rocks and the ratio between the alkalies and silica in their magmas; the more siliceous ones yielding more orthoclase or albite, the less siliceous ones more leucite or nephelite. It is not a definite relationship in rocks generally, and, as Michel Lévy has pointed out, the character of the diagram would not have been altered materially had the vertical ordinates been made to correspond directly to the sum of the alkalies. In this case the curved lines which represent the loci of pure quartz-albite-nephelite rocks and quartz-orthoclase-leucite rocks would be straight lines instead of hyperbolas, as in the diagrams here used. There would be a slightly different vertical spacing of the analyses on individual diagrams. They would be spread more on the left side of the ordinate of 60 per cent SiO_2, and condensed more on the right of it. The multiple diagrams would be more simply constructed. Otherwise the results would be alike.

With diagrams constructed by using ratios between two or more rock components it matters not whether the analyses discussed by it are reduced to anhydrous compounds, or whether their summation is exactly 100. The ratio between the alkalies and silica is not affected by readjusting the analysis. The ordinate of an analysis so located is not changed by readjusting the percentages in the analysis, but the abscissa would be affected by changing the silica percentage. The position of an analysis would be shifted horizontally to the left or right according as the percentage of silica is raised or lowered.

The zero point of each individual diagram is located in the multiple diagram by reference to the silica percentage and the alkali-silica ratio of the analysis it represents. In some instances several individual diagrams belong so close together that they would overlap, so as to prevent their shapes from being easily seen. One or more of them is moved to the nearest available space in the multiple diagram. From this it happens that the distribution of the analyses in the large diagram is not strictly correct in the more crowded portions of it. A more exact representation of the distribution is given in another form of multiple diagrams on a smaller scale, in which round spots take the place of the individual diagrams.

ROCK ANALYSES USED IN CONSTRUCTING DIAGRAMS.

Having described the methods by which the diagrams are constructed, a more important matter to be considered is the data to be used—the rock analyses to be compared by them.

Analyses have been selected from all sources available, but not all analyses. It is important that they be correctly made and from good material. These conditions, however, can not always be recognized or known without careful study of the publications in which the analyses appear, and not always then. The collection is not above criticism in this respect. However, care was exercised to omit obviously defective analyses, as well as those from plainly declared altered rocks, except in cases where the altered form may be assumed to correspond approximately to the fresh rock, with the addition of water of hydration. For the strongly ferromagnesian rocks such analyses have been taken sometimes in default of better.

The analyses represent as many varieties of igneous rocks as could be found, with as wide a range as possible. Many analyses closely similar to those introduced into the large diagrams have been omitted because there was not space for them. Consequently the diagrams do not show the proper proportions between the commoner and rarer varieties of rocks. This can be shown by plotting the loci of all acceptable analyses by means of spots in a multiple diagram of fairly large scale. This has been done in constructing the diagram on Pl. VIII, which is composed of 2,000 analyses.

It was thought unnecessary to reprint the analyses themselves, for the reason that nearly all of them will be found in the collection of rock analyses made by Dr. Henry S. Washington and published by the United States Geological Survey,[a] and a large part of them also in Bulletin of the United States Geological Survey No. 168. Many of them will be found in Rosenbusch's Elemente der Gesteinslehre. So that these collections should be used in connection with the diagrams. For this reason reference is given in many cases to these publications, and to others where numerous analyses are assembled, instead of to the original sources, as the more convenient method of finding them.

A list of the analyses used in the diagrams is given. Their positions on the diagrams may be found by means of the silica percentage and alkali-silica ratio, which are stated in each case, besides the position given them when placed differently.

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[a] Chemical analyses of igneous rocks from 1884 to 1900: Prof. Paper U. S. Geol. Survey No. 14.

They are classified according to the quantitative classification, and the author wishes to express his thanks to Dr. Washington for the labor he has bestowed on the comparison of the list with his collection and for the correction of errors that appeared in the list. He is indebted to him also for valuable additions to it.

The list is far from complete, and petrographers may add to it and to the diagrams data which should have been included. But it seems as though enough has been introduced to accomplish the purpose for which the diagrams were prepared.

In order to shorten the references in the lists, a number of abbreviations are used which are given alphabetically.

ABBREVIATIONS EMPLOYED IN BIBLIOGRAPHIC REFERENCES.

A. G	American Geologist. Minneapolis.
A. J. S	American Journal of Science. New Haven.
A. W. B	Sitzungsberichte der König. Preuss. Akad. der Wissensch. Berlin.
A. W. W	Sitzungsberichte der K. Akad. Wissensch. Wien.
B. C. G. F	Bulletin de la Commission géologique de Finlande. Helsingfors.
B. G. S. A	Bulletin of the Geological Society of America. Rochester.
B. M. A	Bergens Museums Aarbog.
Bull. 168	Bulletin of the U. S. Geological Survey, No. 168. Washington, 1900.
C. G. I	Congrès géologique International, Compte Rendu, VIII session. Paris.
E. K	Die Eruptivgesteine des Kristianiagebietes, W. C. Brögger. Christiania. I, 1894; II, 1895; III, 1898.
G. C	Untersuchung einiger Gesteinssuiten gesammelt in Celebes, von P. and F. Sarasin. C. Schmidt, Wiesbaden, 1901.
G. F. S. F	Geol. Fören. i Stockholm Förhandl.
I. R. A	The igneous rocks of Arkansas: vol. 2 of Ann. Rept. Geol. Surv. Arkansas.
J. G	The Journal of Geology. Chicago.
O. N	Recherches géologiques et pétrographiques sur l'Oural du Nord, Duparc et Pearce. Part I. Geneva, 1902.
M. M	Materiaux pour la Minéralogie de Madagascar, A. Lacroix. Nouvelles Archives du Muséum. 4th series, Vol. I. Paris, 1902.
N. J	Neues Jahrbuch für Mineralogie, Geologie, etc.
Q. J. G. S	Quarterly Journal of the Geological Society of London.
Rosenbusch, El	Rosenbusch. Elemente der Gesteinslehre. Stuttgart, 1898.
R. T	Roth's tables of rock analyses. Beiträge zur Petrographie der Plutonischen Gesteine. Berlin.
S. M. Q	School of Mines Quarterly. New York.
T. M. P. M	Tschermak's Min. u. Petr. Mitth. Vienna.
W. T	Washington's tables of chemical analyses of igneous rocks from 1884 to 1900. Professional Paper U. S. Geological Survey, No. 14, Washington, 1903.
Z. D. g. G	Zeitschrift d. Deutschen geol. Gesellschaft. Berlin.
Z. K	Zeitschrift für Krystallographie.
Z. P. G	Zeitschrift für Praktische Geologie. Berlin.
Fortieth Par	U. S. Geol. Expl. Fortieth Parallel. Washington.

CLASSIFIED LIST OF ANALYSES USED IN CONSTRUCTING DIAGRAMS.

CLASS I. PERSALANE.

ORDER 3. COLUMBARE.

RANG 1. ALASKASE.

SUBRANG 1. ——.

(I. 3, 1, 1.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
79.25	0.057	Porphyry	Harz Mountains	R. T., 1861, 7.

SUBRANG 2. MAGDEBURGOSE.

(I. 3, 1, 2.)

79.75	0.062	Quartz-porphyry	Blowing Rock, Watauga County, N. C.	Bull. 168, 52.— W. T.
78.86	.079	Felsite-porphyry	Fichtelgebirge, Bavaria	R. T., 1879, XX.
76.10	.085	Granite	Crystal Falls district, Mich	Bull. 168, 66.—W. T.
75.39	.080	Rhyolite	Silver Cliff, Colo	Bull. 168, 149.—W. T.
74.40	.079	Granite	Pikes Peak district, Colo	Bull. 168, 142.—W. T.

SUBRANG 3. ALASKOSE.

(I. 3, 1, 3.)

80.24	0.070	Granite	Wexford, Ireland	R. T., 1861-2.
79.57	.070	Rhyolite	Montgomery County, N. C	Bull. 168, 53.—W. T.
77.68	.077	Granitite	Eldorado County, Cal	Bull. 168, 199.—W. T.
77.68	.075 (77.6)	Quartz-porphyry	Tryberg Fall, Black Forest	N. J., 1883, II, 29.—W. T.
77.59	.059	Rhyolite	Hauraki Goldfield, New Zealand	Q. J. G. S., 1899, LV, 467.—W. T.
77.33	.079 (.078)	Alaskite	Tordrillo Mountains, Alaska	Bull. 168, 228.—W. T.
77.20	.080	Quartz-porphyry	Kroftkollen, Norway	Z. K., XVI, 77.—W. T.
77.05	.080	Aplite	Butte, Mont	Bull. 168, 118.—W. T.
77.03	.081 (76.8-.082)	Granitite	Pikes Peak district, Colo	Bull. 168, 142.—W. T.
77.02	.077 (77.1)	Granite	Platte Canyon, Colo	Bull. 168, 164.—W. T.
76.87	.078	Aplite	Butte, Mont	Bull. 168, 118.—W. T.
76.73	.077 (76.6)	Aplitic granophyre	Hennum, Norway	Z. K., XVI, 77.—W. T.
76.10	.063	Muscovite-granite	Omeo, Victoria	Trans. R. S. Vict.—W. T.
75.84	.081	Tordrillite	Tordrillo Mountains, Alaska	Bull. 168, 229.—W. T.
75.52	.080 (75.7)	Obsidian	Obsidian Cliff, Yellowstone Park	Bull. 168, 104.—W. T.
74.70	.083	do	do	Do.
74.24	.069	Rhyolite	Plumas County, Cal	Bull. 168, 178.—W. T.
73.11	.082 (73.0)	Pitchstone	Rosita, Colo	Bull. 168, 150.—W. T.

SUBRANG 4. ——.

(I. 3, 1, 4.)

83.08	0.054	Spherulitic rock	Wales	Teall, British Petrography, 339.
82.80	.049	Perlite	Monte Menone	R. T., 1869, XC.
76.00	.067	Granite	Plumas County, Cal	Bull. 168, 187.—W. T.
75.19	.076 (75.1)	Rhyolite	Madison Plateau, Yellowstone Park	Bull. 168, 105.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 5. WESTPHALOSE.

(I. 3, 1, 5.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
83.57	0.063	Quartz-keratophyre	Westphalia	N. J., 1893, VIII, 616.—W. T.
80.42	.059	do	do	N. J., 1893, VIII, 632.—W. T.
77.32	.081 (.083)	Granite	Roddö, Sweden	W. T.

RANG 2. ALSBACHASE.

SUBRANG 2. MIHALOSE.

(I. 3, 2, 2.)

73.15	0.055	Rhyolite	Nagy-Mihaly, Hungary	W. T.
73.07	.074	do	Washoe, Nev	Bull. 168, 174.—W. T.
72.68	.054	do	Nagy-Mihaly, Hungary	W. T.
70.59	.057	do	do	Do.

SUBRANG 3. TEHAMOSE.

(I. 3, 2, 3.)

79.95	0.049	Felsite-porphyry	Bohemia	R. T., 1884, XVIII.
77.34	.069	Aplite	Kirnechthal, Vosges	Rosenbusch, El., 207.
76.12	.059	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
75.89	.069 (75.8)	Rhyolite	Mount Sheridan, Yellowstone Park	Bull. 168, 105.—W. T.
75.34	.076	do	Elephants Back, Yellowstone Park	Do.
75.21	.072	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.65	.074	Rhyolite	Tehama County, Cal	Bull. 168, 178.—W. T.
74.41	.067	Granite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.34	.072	Rhyolite	Butte district, Mont	Bull. 168, 119.—W. T.
73.62	.079 (73.7)	do	Tehama County, Cal	Bull. 168, 178.—W. T.
72.37	.058	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
72.15	.067	do	do	Do.
72.04	.058	do	do	Do.
72.01	.073	Quartz-porphyry	Eureka, Nev	U. S. G. S., Mon. XX, 228.
71.45	.054	Granitite	Sykesville, Md	Bull. 168, 47.—W. T.

SUBRANG 4. ALSBACHOSE.

(I. 3, 2, 4.)

78.75	0.052	Granite	Storgord, Finland	R. T., 1869, XL.
77.35	.052	do	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
74.65	.064	Granitite	do	Do.
74.13	.077	Alsbachite	Melibocus, Odenwald	Rosenbusch, El., 207.—W. T.
73.08	.080 (72.9)	Rhyolite	Waihi, Hauraki, New Zealand	Q. J. G. S., 1899, LV, 467.—W. T.
72.89	.056	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.

SUBRANG 5. YUKONOSE.

(I. 3, 2, 5.)

74.79	0.067	Tonalite-aplite	Yukon River, Alaska	Bull. 168, 229.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. RIESENASE.

SUBRANG 2. ——.

(I. 3, 3, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
72.11	0.041	"Schliere" in granite	Riesengebirge, Silesia	N. J., 1898, XII, 235.—W. T.
71.14	.055	Toscanite	Rocca Strada, Italy	J. G., V, 363.—W. T.
66.86	.052	Granite-porphyry	Nieder Modau, Hesse	W. T.

SUBRANG 3. RIESENOSE.

(I. 3, 3, 3.)

76.82	0.037	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
75.27	.036	Granite	do	Do.
75.21	.048	Granitite	do	Do.
73.00	.049	Toscanite	Rocca Strada, Italy	J. G., V, 363.—W. T.
72.92	.040	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
72.71	.038	do	do	Do.
69.04	.047	do	do	N. J., 1898, XII, 234.—W. T.

SUBRANG 4. ——.

(I. 3, 3, 4.)

76.13	0.055 (76.2)	Granite	Riesengebirge, Silesia	N. J., 1898, XII, 233.—W. T.
72.81	.041	Granitite	do	N. J., 1898, XII, 232.—W. T.

SUBRANG 5. VULCANOSE.

(I. 3, 3, 5.)

72.24	0.062	Quartz-diorite-porphyry.	Calaveras County, Cal	Bull. 168, 203.—W. T.
66.99	.051	Vulcanite	Vulcano, Lipari	B. G. S. A., V, 601.—W. T.

RANG 4. ——.

SUBRANG 2. ——

(I. 3, 4, 2.)

68.87	0.028	"Schliere" in granite	Riesengebirge, Silesia	N. J., 1898, XII, 235.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

Order 4. Britannare.

Rang 1. Liparase.

Subrang 1. Lebachose.

(I. 4, 1, 1.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
69.06	0.117 (69.3)	Quartz-orthoclasite...	Thüringerwald, Prussia..............	W. T.
68.18	.107	Quartz-porphyry	Hummelberg, Prussia................	Do.

Subrang 2. Omeose.

(I. 4, 1, 2.)

75.20	0.096	Rhyolite	Silver Cliff, Colo......................	Bull. 168, 149.—W. T.
75.07	.084	.....do	Pine Nut Canyon, Nev	Fortieth Par., I, 652.
74.62	.095	.....do	Humboldt Sink Group, Nev..........	Do.
74.24	.089	Rapakiwi	Livland, Finland.........................	R. T., 1878, X.
71.09	.112	Aplite	Satteljoch, Predazzo, Tyrol	K. A. W. W., CXI, I, 266.
70.91	.121	Graphic granite	Omeo, Victoria........................	Trans. R. S. Vict.—W. T.
68.99	.115	Pitchstone	Ponza, Italy..........................	R. T., 1879, LII.
68.87	.084	Granite...............	Omeo, Victoria........................	Trans. R. S. Vict.—W. T.

Subrang 3. Liparose.

(I. 4, 1, 3.)

77.61	0.088	Granite...............	Cape Ann, Mass.......................	J. G. VI, 793.—W. T.
76.49	.092	Paisanite.............	Magnolia, Mass........................	J. G. VII, 113.—W. T.
76.33	.092	Graphic granite......	Hochland	R. T., 1869, XLII.
76.30	.088	Alaskite..............	Alaska	Bull. 168, 228.—W. T.
76.29	.091	Obsidian	Obsidian Hill, N. Mex................	Bull. 168, 172.—W. T.
76.05	.092	Aplitic granophyre...	Konerudwege, Norway...............	Z. K., XVI, 77.—W. T.
75.71	.094 (75.6)	Rhyolite	Great Paint Pots, Yellowstone Park..	Bull. 168, 105.—W. T.
75.44	.094	Comendite	Iskagan Bay, Siberia..................	A. J. S., XII, 1902, 180.—W. T.
75.44	.089	Rhyolite	Fish Creek Mountains, Nev	Fortieth Par., I, 652.
75.30	.082	.....do	Rimini, Mont	Bull. 168, 119.—W. T.
75.17	.085	Granitite	Pikes Peak district, Colo......... ...	Bull. 168, 142.—W. T.
74.90	.094	Rhyolite..............	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
74.87	.084	Granite...............	Brookville, Md.........................	Bull. 168, 46.—W. T.
74.76	.098	Comendite	Comende, San Pietro, Sardinia.......	Rosenbusch, El., 257.—W. T.
74.45	.090	Rhyolite..............	Chalk Mountain, Colo	Bull. 168, 156.—W. T.
74.05	.096	Obsidian	Mono Craters, Cal.....................	Bull. 168, 219.—W. T.
73.93	.100	Granite...............	Quincy, Mass..........................	J. G., VI, 793.—W. T.
73.69	.100	Granite-porphyry.....	Mount Ascutney, Vt	Bull. 168, 25.—W. T.
73.51	.094 (73.4)	Granitite	Pikes Peak district, Colo.............	Bull. 168, 142.—W. T.
73.35	.106	Paisanite.............	Mosques Canyon, Tex.................	T. M. P. M., XV, 439.—W. T.
73.09	.085	Granite-porphyry.....	Albany, N. H..........................	A. J. S., XX, 1881, 25.
73.03	.104	Syenite-porphyry.....	Mount Ascutney, Vt...................	Bull. 168, 24.—W. T.
72.88	.098	Aplite-granite	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
72.48	.099	Granite...............	.....do	Do.
72.35	.098	.....do	Ironton, Mo	Bull. 168, 60.—W. T.
72.26	.101	.....do	Albany, N. H..........................	A. J. S., XXI, 1881, 25.
72.06	.107	.....do	Stony Creek, Conn	B. G. S. A., X, 375.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

Subrang 3. Liparose—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
71.90	.102	Granitite	Mount Ascutney, Vt	Bull. 168, 24.—W. T.
71.88	.095	Porphyry	Ironton, Mo	Bull. 168, 60.—W. T.
71.67	.101	Quartz-porphyry	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
71.56	.086	Pitchstone	Silver Cliff, Colo	Bull. 168, 159.—W. T.
71.49	.109	Quartz-porphyry	Gislerud, Norway	Z. K., XVI, 46.—W. T.
71.07	.087	Granite-porphyry	Albany, N. H	A. J. S., XXI, 1881, 25.
70.92	.096 (70.7)	Rhyolite	Upper Geyser Basin, Yellowstone Park.	Bull. 168, 104.—W. T.
70.23	.113	Keratophyre	Marblehead Neck, Mass	Bull. 168, 34.—W. T.
70.09	.092	Orthoclase-porphyry	Cornon, Tyrol	R. T., 1879, XXVIII.
70.01	.118	Obsidian	Palmerola, Italy	R. T., 1879, LII.
69.91	.119	Ægirite-granite	Miask, Ural Mountains	A. J. S., XIII, 1902, 180.—W. T.
69.89	.098	Rhyolite	Nathrop, Colo	Bull. 168, 164.—W. T.
68.95	.144	Grorudite	W. Aker, Norway	E. K., I, 199.—W. T.
68.71	.114	Quartz-pantellerite	Vieja Mountains, San Carlos, Tex	Bull. 168, 61.—W. T.
68.65	.110 (68.5)	Granite-syenite-porphyry.	Little Rocky Mountains, Mont	Bull. 168, 134.—W. T.
68.34	.129	Quartz-syenite	Bearpaw Mountains, Mont	Bull. 68, 135.—W. T.
66.40	.097 (66.7)	Quartz-syenite-porphyry.	Fjelebua, Norway	Z. K., XVI, 46.—W. T.

Subrang 4. Kallerudose.

(I. 4, 1, 4.)

75.92	0.093 (75.8–.094)	Granitite	Pikes Peak district, Colo	Bull. 168, 142.—W. T.
73.61	.089	Rhyolite	Oyacachi, South America	R. T., 1879, LIV.
73.50	.095 (73.8)	Quartz-bearing bostonite.	Ampangarinana, Madagascar	M. M., 55.
72.56	.099 (72.8)	Rhyolitic pitchstone	Castle Mountain district, Mont	Bull. 168, 129.—W. T.
72.46	.095	Rhyolite	Guomani, Ecuador, South America	R. T., 1879, LIV.
71.65	.119	Soda granite	Hougnatten, Norway	E. K., I, 198.—W. T.

Subrang 5. Noyangose.

(I. 4, 1, 5.)

77.66	0.087 (77.9–.086)	Quartz-keratophyre	Omeo, Victoria	Rosenbusch, El., 260.—W. T.
75.78	.091	Granite	Rice Point, Duluth, Minn	21st Ann. Rept., Surv. Minn., 41.—W. T.
75.46	.097	Soda-rhyolite	Berkeley, Cal	Rosenbusch, El., 260.—W. T.

Rang 2. Toscanase.

Subrang 2. Dellenose.

(I. 4, 2, 2.)

69.19	0.102	Granite	Tryberg Fall, Schwarzwald	N. J., 1883, II.
68.36	.078	Dellenite	Dellen, Helsingland, Sweden	E. K., II, 59.—W. T.
66.24	.093	Toscanite	Monte Cucco, Italy	J. G., V, 362.—W. T.
65.19	.093	do	Tolfa, Italy	Do.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. TOSCANOSE.

(I. 4, 2, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
76.48	0.087	Aplite	Dargo, Victoria	Trans. R. S. Vict.—W. T.
76.03	.081	do	Sierra County, Cal	Bull. 168, 192.—W. T.
76.00	.087	Granodiorite-aplite	Downieville area, Cal	J. G., VII, 160.—W. T.
75.97	.079 (76.1-.078)	Aplite	Sierra County, Cal	Bull. 168, 192.—W. T.
75.74	.086	Granite	Lier, Norway	Z. K., XVI, 77.—W. T.
75.08	.084 (75.0)	Obsidian	Laguna de Maricunga, Chile	Z. D. J., G. LI, 4.
75.01	.086 (75.1-.088)	Alaskite	Alaska	Bull. 168, 228.—W. T.
74.95	.088	Rhyolite	Montezuma Mountains, Nev	Fortieth Par., I, 652.
74.60	.081	do	Shasta County, Cal	Bull. 168, 178.—W. T.
74.49	.088 (74.6)	do	Thomas Range, Utah	Bull. 168, 168.—W. T.
74.37	.085	Granitite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
73.84	.083	Rhyolite-perlite	Midway Basin, Yellowstone Park	Bull. 168, 108.—W. T.
73.70	.092	Granite	Peterhead, Scotland	R. T., 1884, XIV.
73.64	.088	Rhyolite	Lassen trail, Tehama County, Cal	Bull. 168, 178.—W. T.
73.51	.097	Obsidian	Modoc County, Cal	Bull. 168, 217.—W. T.
73.38	.080	Granite	Lake Raslangen, Sweden	W. T.
73.12	.087	Quartz-porphyry	Little Belt Mountains, Mont	Bull. 168, 125.—W. T.
72.57	.090	Granite	Guilford, Md	Bull. 168, 46.—W. T.
72.40	.086	Rhyolite	Mount Stover, Cal	Bull. 168, 178.—W. T.
71.85	.087 (72.0)	do	Tower Creek, Yellowstone Park	Bull. 168, 104.—W. T.
71.79	.082 (71.7)	Granitite	Woodstock, Md	Bull. 168, 46.—W. T.
71.78	.085	Granite	Cottonwood Canyon, Utah	Fortieth Par., I, 110.
71.53	.070	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
71.12	.098	Rhyolite	Ponza, Italy	R. T., 1879, LII.
71.08	.084 (71.0)	Granodiorite	El Capitan, Yosemite, Cal	Bull. 168, 207.—W. T.
70.87	.092	Rhyolite	Pennsylvania Hill, Silver Cliff, Colo	Bull. 168, 149.—W. T.
70.75	.080	Granite	Amador County, Cal	Bull. 168, 200.—W. T.
70.56	.105 (70.7)	Rhyolite	Ponza, Italy	
70.54	.107	Ægirite-granite	Löken, Norway	Z. K., XVI, 57.—W. T.
70.45	.084	Granite	Dorseys Run, Md	Bull. 168, 47.—W. T.
70.29	.101	Rhyolite	Harlequin Canyon, Nev	Fortieth Par., I, 652.
69.96	.089	Dacite	Washoe, Nev	Bull. 168, 174.—W. T.
69.95	.098 (70.1)	Quartz-porphyry	Butte district, Mont	Bull. 168, 119.—W. T.
69.94	.092	Granite	Ironton, Mo	Bull. 168, 60.—W. T.
69.68	.087	Granite-porphyry	Little Belt Mountains, Mont	Bull. 168, 125.—W. T.
69.52	.108	Trachyte	Pikes Peak district, Colo	Bull. 168, 145.—W. T.
69.45	.097	Rhyolo-trachyte	Sunset Peak, Mont	Bull. 168, 106.—W. T.
68.88	.100	Quartz-syenite-porphyry.	Squam Light, Mass	J. G., VII, 109.—W. T.
68.68	.077	Granite	Eureka, Nev	U. S. G. S., Mon. XX, 228.
68.60	.107 (68.7)	Granite-porphyry	Little Belt Mountains, Mont	Bull. 168, 125.—W. T.
68.58	.100	Granite	West Humboldt Mountains, Nev	Fortieth Par., I, 110.
68.55	.095	do	Shap, England	Q. J. G. S., 47, 276
68.42	.083 (68.2)	Quartz-monzonite	Hailey, Idaho	Bull. 168, 137.—W. T.
68.40	.112 (68.2)	Granite	Millstone Point, Conn	B. G. S. A., X, 375.—W. T.
68.36	.105	Nordmarkite	Gloucester, Mass	J. G., VI, 800.—W. T.
67.45	.084	Granodiorite	Eldorado Canyon, Cal	Bull. 168, 199.—W. T.
67.44	.104	Granite-syenite-porphyry.	Little Belt Mountains, Mont	Bull. 168, 127.—W. T.
67.12	.082	Granite	Boulder, Mont	Bull. 168, 118.—W. T.
67.04	.107	Quartz-syenite-porphyry.	Little Belt Mountains, Mont	Bull. 168, 127.—W. T.
66.60	.111	Akerite	Gloucester, Mass	J. G., VI, 798.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. TOSCANOSE—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.12	.123 (66.8)	Trachyte	Wicher Mountain, Colo	Bull. 168, 145.—W. T.
65.58	.094	do	Monte Amiata, Italy	Rosenbusch, El., 269.—W. T.
65.32	.096	do	do	Do.
65.05	.092	Toscanite	do	J. G., V, 362.—W. T.
64.76	.094	Trachyte	do	Rosenbusch, El., 269.—W. T.
64.64	.114 (64.5)	Syenite	Little Belt Mountains, Mont	Bull. 168, 125.—W. T.
64.62	.118	Diorite	Mount Ascutney, Vt	Bull. 168, 25.—W. T.
64.57	.095	Toscanite	Bracciano, Italy	J. G., V, 362.—W. T.
64.49	.103	Porphyrite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
62.33	.110	Latite	Clover Meadow, Tuolumne County, Cal.	Bull. 168, 205.—W. T.

SUBRANG 4. LASSENOSE.

(I. 4, 2, 4.)

75.50	0.083	Rhyolite	Obsidian Cliff, Yellowstone Park	Bull. 168, 104.—W. T.
73.27	.077	Granite	Florence, Mass	Bull. 168, 30.—W. T.
73.00	.075	do	Rocklin, Cal	Bull. 168, 198.—W. T.
72.59	.083	Obsidian	Willow Park, Yellowstone Park	Bull. 168, 104.—W. T.
71.74	.075	Granitite	Riesengebirge, Silesia	N. J., 1898, XII, 232.—W. T.
71.19	.073	Quartz-porphyrite	Calaveras County, Cal	Bull. 168, 203.—W. T.
70.36	.082	Granodiorite	Enterprise, Butte County, Cal	Bull. 168, 190.—W. T.
69.93	.109	Granite-porphyry	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
69.66	.084	Dacite	Lassen Peak, Cal	Fortieth Par., I, 652.
69.56	.076	do	Colombia, South America	J. G., I, 171.—W. T.
69.51	.083	do	Lassen Peak, Cal	Bull. 168, 179.—W. T.
69.00	.126	Quartz-lindoite	W. Aker, Norway	E. K., I, 196.—W. T.
68.72	.084 (68.8)	Dacite	Lassen Peak, Cal	Bull. 168, 180.—W. T.
68.65	.084	Quartz-monzonite	Sierra County, Cal	Bull. 168, 192.—W. T.
68.32	.086	Dacite	Lassen Peak, Cal	Bull. 168, 179.—W. T.
68.10	.088	do	Shasta County, Cal	Bull. 168, 180.—W. T.
67.89	.088	Andesite	Buntingville, Cal	Bull. 168, 181.—W. T.
67.55	.087 (67.2)	Pitchstone	Butte district, Mont	Bull. 168, 119.—W. T.
67.49	.085 (67.6)	Dacite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
67.49	.112	Mica-dacite	Silver Cliff, Colo	Bull. 168, 149.—W. T.
67.42	.116	Augite-soda-granite	Kekequabic Lake, Minn	A. G., XI, 385.—W. T.
67.01	.120	Alaskite-porphyry	Alaska	Bull. 168, 228.—W. T.
66.46	.104	Dacite	Rosita, Colo	Bull. 168, 149.—W. T.
66.30	.098	Dacite-porphyry	Shasta County, Cal	Bull. 168, 177.—W. T.
66.28	.094 (66.5)	Porphyrite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
65.87	.099	Feldspar-porphyry	Castle Mountain district, Mont	Bull. 168, 130.—W. T.
65.78	.121	Mica-andesite	San Mateo Mountain, N. Mex	Bull. 168, 170.—W. T.
65.64	.108	Andesite-porphyry	Gray Peak, Yellowstone Park	Bull. 168, 107.—W. T.
64.98	.109	Oligoclasite	Preston, Norway	B. M. A., 1898, VII, 47.—W. T.
62.58	.109	Syenite-porphyry	Yogo Peak, Mont	Bull. 168, 127.—W. T.

SUBRANG 5. MARIPOSOSE.

(I. 4, 2, 5.)

74.21	0.100	Soda-granite	Mariposa County, Cal	Bull. 168, 207.—W. T.
67.88	.084 (67.8)	Granite	Cavaura River, British Guiana	W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. COLORADASE.

SUBRANG 3. AMIATOSE.

(I. 4, 3, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
68.97	0.075	Granite	Lower Elsass, Vosges	Rosenbusch, El., 78.
65.53	.085	Trachyte	Monte Amiate, Italy	Rosenbusch, El., 269.—W. T.
65.36	.085	Quartz-porphyrite	Mount Carbon, Colo	Bull. 168, 160.—W. T.
65.13	.082	Andesite-perlite	Eureka, Nev	U. S. G. S., Mon. XX, 264.—W. T.
63.17	.088	Dacite	Pergamon, Asia Minor	A. J. S., III, 1897, 45.—W. T.
61.93	.085	Andesite	Kara Tash, Asia Minor	A. J. S., III, 1897, 45.—W. T.

SUBRANG 4. YELLOWSTONOSE.

(I. 4, 3, 4.)

68.41	0.084	Dacite	Colombia, South America	J. G., I, 171.—W. T.
68.10	.065	Diorite	Ono, Cal	Bull. 168, 177.—W. T.
68.12	.078	Andesite	Shasta County, Cal	Bull. 168, 183.—W. T.
67.30	.075	Dacite	Colombia, South America	J. G., I, 171.—W. T.
66.94	.070	Andesite	Sierra County, Cal	Bull. 168, 193.—W. T.
66.65	.082	Quartz-diorite-porphyry.	.....do	Bull. 168, 192.—W. T.
66.65	.074	Granodiorite	Nevada City, Cal	Bull. 168, 194.—W. T.
65.71	.065	Banatite	Banat, Hungary	Rosenbusch, El., 140.
65.66	.072	Dacite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
65.63	.080	Andesite	Fan Creek, Yellowstone Park	Bull. 168, 107.—W. T.
65.60	.086 (65.7)	Quartz-mica-diorite	Electric Peak, Yellowstone Park	Bull. 168, 88.—W. T.
64.85	.084	.....do	.....do	Do.
64.61	.088	Andesite	Crescent Hill, Yellowstone Park	Bull. 168, 108.—W. T.
64.52	.080	.....do	Mount Shasta, Cal	Bull. 168, 176.—W. T.
64.48	.076 (64.7)	.....do	.....do	Do.
64.27	.081	.....do	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
64.24	.078 (64.1)	Dacite-porphyry	Shasta County, Cal	Bull. 168, 177.—W. T.
63.81	.079	Dacite	Mill Creek, Shasta County, Cal	Bull. 168, 180.—W. T.
63.42	.098	Quartz-diorite-porphyry.	Crandall Basin, Wyo	Bull. 168, 94.—W. T.
63.30	.087	Andesite	Mount Rose, Washoe, Nev	Fortieth Par. I, 604.
62.91	.094	Granitite	Dorseys Run, Md	Bull. 168, 47.—W. T.
62.85	.085	(?) Porphyrite-diorite	Mount Marcellina, Colo	Bull. 168, 160.—W. T.
61.42	.078	Porphyrite	Storm Ridge, Colo	Do.

SUBRANG 5. AMADOROSE.

(I. 4, 3, 5.)

69.66	0.074	Quartz-diorite-aplite	Amador County, Cal	Bull. 168, 201.—W. T.
69.34	.066	Granite	Saganaga Lake, Minn	21st Ann. Rept. Geol. Surv. Minn., 43.—W. T.

RANG 4. ———.

SUBRANG 3. ———.

(I. 4, 4, 3.)

65.81	0.047	Granite	Hochwald, Vosges	Rosenbusch, Steiger Schiefer (Strassburg, 1877), 167.

Classified list of analyses used in constructing diagrams—Continued.

ORDER 5. CANADARE.

RANG 1. NORDMARKASE.

SUBRANG 3. PHLEGROSE.

(I. 5, 1, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.13	0.130	Quartz-syenite	Fjelebua, Norway	Z. K., XVI, 46.—W. T.
66.03	.132 (65.9)	Trachyte	Game Ridge, Custer County, Colo	Bull. 168, 147.—W. T.
65.43	.131	Syenite	Mount Ascutney, Vt	Bull. 168, 24.—W. T.
64.88	.128	Syenite-porphyry	.....do	Bull. 168, 25.—W. T.
64.04	.160	Nordmarkite	Tonsenas, Norway	Z. K., XVI, 54.—W. T.
63.71	.159	Pulaskite	Salem Neck, Mass	J. G., VI, 806.—W. T.
62.30	.142	Bostonite	Gran, Norway	E. K., III, 204.—W. T.
61.92	.151	Pulaskite	Lokobé, Madagascar	M. M., 204.
61.88	.176	Trachyte	Marecocco, Italy	A. J. S., VIII, 1899, 289.—W. T.
61.62	.170 (61.2)	.....do	Monte Rotaro, Italy	Do.
61.45	.143 (61.3)	.....do	Maros, Celebes	G. C., 16.
61.05	.166	Sölvsbergite	Coney Island, Mass	J. G., VII, 118.—W. T.
60.33	.193	Trachyte	Monte Nuovo, Italy	A. J. S., VIII, 1899, 287.—W. T.
60.13	.165	Nephelite-syenite	Fourche Mountain, Ark	J. G., IX, 610.—W. T.
60.02	.147	Syenite-keratophyre	Harz Mountains	R. T., 1884, XXII.
59.79	.186	Trachyte	Monte Nuovo, Italy	A. J. S., VIII, 1899, 287.—W. T.
59.70	.164	Nephelite-syenite	Fourche Mountain, Ark	I. R. A., 88.—W. T.
58.75	.176	Umptekite	Cabo Frio, Brazil	T. M. P. M., XX, 248.—W. T.
57.18	.171	Trachyte	Highwood Mountains, Mont	Bull. 168, 131.—W. T.

SUBRANG 4. NORDMARKOSE.

(I. 5, 1, 4.)

66.50	0.162	Lestiwarite	Kvella, Norway	E. K., III, 216.—W. T.
66.22	.149 (66.4)	Quartz-syenite-porphyry.	Bearpaw Mountains, Mont	Bull. 168, 135.—W. T.
66.06	.151	Liparite	Hohenburg, near Bonn, Prussia	R. T., 1884, XLVIII.
65.51	.143	Phonolitic andesite	San Mateo Mountains, N. Mex	Bull. 168, 170.—W. T.
65.43	.140 (65.1)	Nordmarkite	Shefford Mountain, Quebec	J. G., XI, 271.
64.92	.146	Quartz-sölvsbergite	Gran, Norway	E. K., I, 78.—W. T.
64.54	.157	Pulaskite	Lovasbucht, Norway	E. K., III, 198.—W. T.
64.33	.151	Acmite-trachyte	Crazy Mountains, Mont	Bull. 168, 123.—W. T.
63.76	.161 (63.4)	Syenite	Ahvenvaara, Finland	B. C. G. F., 11, 34.—W. T.
63.20	.164	Nordmarkite	Tonsenas, Norway	Z. K., XVI, 54.—W. T.
63.09	.164 (63.6)	Pulaskite	Salem Neck, Mass	J. G., VI, 806.—W. T.
62.17	.156	Acmite-trachyte	Crazy Mountains, Mont	Bull. 168, 123.—W. T.
61.67	.169	Keratophyre	Harz Mountains	R. T., 1884, XXII.
61.54	.180	Phonolite	Zittau, Saxony	R. T., 1861, 23.
61.08	.185	.....do	Black Hills, S. Dak	A. J. S., XLVII, 1894, 344.—W. T.
60.39	.184	Litchfieldite	Litchfield, Me	Bull. 168, 21.—W. T.
60.11	.161 (59.9)	Bostonite	Hedrum, Norway	E. K., III, 204.—W. T.
60.05	.157 (60.3)	Tinguaite	Gales Point, Mass	J. G., VII, 481.—W. T.
59.62	.178	Nephelite-syenite	Saline County, Ark	I. R. A., 135.—W. T.
59.31	.174	Foyaite	Great Haste Island, Mass	J. G., VII, 481.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

Subrang 5. Tuolumnose.

(I, 5, 1, 5.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
67.58	0.165	Albitite	Tuolumne County, Cal	Bull. 168, 204.—W. T.
66.09	.162	.....do	Koswinsky, Ural Mountains	O. N., 169.

Rang 2. Pulaskase.

Subrang 2. Vulsinose.

(I. 5, 2, 2.)

58.48	0.165	Leucite-trachyte (?)	Rocca Monfina, Italy	J. G., V, 370 —W. T.
58.21	.142	Vulsinite	Bolsena Monfina, Italy	J. G., V, 358.—W. T.
57.82	.156	.....do	Vetrella, Italy	Do.
55.17	.150	Leucite-trachyte	San Rocco, Italy	J. G., V, 370.—W. T.

Subrang 3. Pulaskose.

(I. 5, 2, 3.)

65.54	0.135	Quartz-syenite	Highwood Mountains, Mont	W. T.
62.64	.119	Andesite (?)	Pikes Peak district, Colo	Bull. 168, 145.—W. T.
61.87	.145	Trachyte	Ischia, Italy	R. T., 1873, XXXVIII.
61.55	.141	.....do	.....do	R. T., 1873, XXXVI.
60.89	.131	Quartz-banakite	Ishawooa Canyon, Wyo	Bull. 168, 102.—W. T.
60.20	.165	Pulaskite	Fourche Mountain, Ark	J. G., IX, 609.—W. T.
60.03	.154	.....do	.....do	I. R. A., 88.—W. T.
59.51	.158	Leucite-trachyte	Viterbo, Italy	J. G., V, 370.—W. T.
59.28	.149	Nephelite-syenite	Fourche Mountain, Ark	I. R. A., 88.—W. T.
57.15	.149	Trachy-dolerite	Maros, Celebes	G. C., 14.
56.45	.175	Sodalite-syenite	Square Butte, Mont	Bull. 168, 134.—W. T.
55.52	.146	Bostonite	Gentungen, Celebes	G. C., 20.

Subrang 4. Laurvikose.

(I. 5, 2, 4.)

65.41	0.139	Trachyte	Game Ridge, Custer County, Colo	Bull. 168, 147.—W. T.
64.80	.125	Domite	Puy de Dome, France	R. T., 1869, CXVIII.
64.63	.132	Quartz-syenite	Fourche Mountain, Ark	I. R. A., 96.—W. T.
63.49	.133	Andesite	Custer County, Colo	Bull. 168, 148.—W. T.
61.47	.120	.....do	Pantellaria, Italy	Z. K., VIII, 155.
61.43	.133	.....do	.....do	Z. K., VIII, 164.
61.05	.147	Trachyte	Ischia, Italy	R. T., 1873, XXXVIII.
60.98	.142 (59.9)	Augite-porphyrite	Henry Mountains, Utah	Bull. 168, 167.—W. T.
60.72	.142	Rhombenporphyry	Nötterö, Norway	Z. K., XVI, 35.—W. T.
60.45	.168	Nordmarkite	Aneröd, Norway	Z. K., XVI, 54.—W. T.
60.24	.170	Augite-andesite	Pantellaria	Z. K., VIII, 155.
59.96	.165	Pulaskite	Shefford Mountain, Quebec	J. G., XI, 271.
59.38	.125	Tönsbergite	Tönsberg, Norway	E. K., III, 375.—W. T.
58.94	.109	Andesite	Silver Cliff, Colo	Bull. 168, 148.—W. T.
58.88	.141	Laurvikite	Laurvik, Norway	Z. K., XVI, 30.—W. T.
58.82	.155	Rhombenporphyry	Tönsberg, Norway	Z. K., XVI, 35.—W. T.
57.59	.139	.....do	Nötterö, Norway	Do.
57.44	.157	Pulaskite	Mount Johnson, Quebec	J. G., XI, 271.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 4. LAURVIKROSE—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
57.33	.153 (57.1)	Rhombenporphyry	Nötterö, Norway	Z. K., XVI, 35.—W. T.
57.12	.138	Laurvikite	Fredriksvärn, Norway	Z. K., XVI, 30.—W. T.
56.85	.144	.....do	Nötterö, Norway	Do.
56.25	.155 (55.9)	Micromonzonite	Ambodimadiro, Madagascar	M. M., 204.
56.19	.156	Tephritic trachyte	Columbretes Islands, Spain	T. M. P. M., XVI, 314.—W. T.
54.00	.162	Rhombenporphyry	Brumunthal, Norway	Z. K., XVI, 28.—W. T.

SUBRANG 5. ——.

(I. 5, 2, 5.)

62.90	0.135	Diorite	Jablanica, Herzegovina	W. T.
60.13	.164	Keratophyre	New Haven, Conn	A. J. S., III, 1897, 291.—W. T.

RANG 3. ——.

SUBRANG 2. ——.

(I. 5, 3, 2.)

59.33	0.135 (59.5)	Augite-syenite	Mazaruni district, British Guiana	W. T.

SUBRANG 3. ——.

(I. 5, 3, 3.)

59.26	0.139	Andesite	Table Mountain, Colo	Bull. 168, 141.—W. T.

SUBRANG 4. ——.

(I. 5, 3, 4.)

58.28	0.112	Diabase-porphyrite	Crazy Mountains, Mont	Bull. 168, 121.—W. T.

RANG 4. LABRADORASE.

SUBRANG 3. LABRADOROSE.

(I. 5, 4, 3.)

55.01	0.086	Anorthosite	Turtschinka, Wolynien, Russia	W. T.
54.62	.093	.....do	New York State	N. J., 1893, VIII, 494.
54.45	.122	.....do	Rawdon, Canada	Do.
53.53	.090 (53.6)	.....do	Pököla, Finland	W. T.
53.43	.099	.....do	Labrador, Canada	N. J., 1893, VIII, 494.—W. T.
53.42	.096	.....do	Ogne, Norway	B. M. A., 1896, V, 96.—W. T.
52.61	.092	.....do	Ekersund, Norway	B. M. A., 1896, V, 79.—W. T.
49.78	.091	.....do	Carlton Peak, Minn	Am. Geol., XXVI, 281.—W. T.
47.25	.056	.....do	Beaver Bay, Lake Superior	U. S. G. S., Mon. V, 438.

RANG 5. CANADASE.

(I. 5, 5.)

47.32	0.048 (47.4)	Anorthosite	South Sherbrooke, Ontario	Am. Geol., XXIV, 280.—W. T.
46.24	.044	.....do	Seine River, Canada	J. G., IV, 909.—W. T.
45.78	.036	.....do	Monhegan Isle, Me	Am. Geol., XXVI, 340.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

ORDER 6. RUSSARE.

RANG 1. MIASKASE.

SUBRANG 3. BEEMEROSE.

(I. 6, 1, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
60.42	0.184	Nephelite-syenite	Moita, Foya, Portugal................	T. M. P. M., XVI, 225.—W. T.
59.20	.189 (59.1)	Microditroite.........	Nosy Komba, Madagascar............	M. M., 169.
58.89	.180	Leucite-tinguaite-vitrophyre.	Picota, Portugal.......................	T. M. P. M., XVI, 252.—W. T.
58.72	.199 (58.8-.200)	Ditroite...............	Nosy Komba, Madagascar............	M. M., 204.
58.00	.199	Phonolite	Maros, Celebes	G. C., 18.
55.87	.201 (55.3)	Leucite-phonolite	Lake Bracciano, Italy	J. G., V., 370.—W. T.
55.38	.207	Foyaite...............	East Cape, Siberia.....................	A. J. S., XIII, 1902, 176.—W. T.
53.56	.229 (53.1)	Nephelite-syenite	Beemerville, N. J.......................	Bull. 168, 39.—W. T.
53.09	.226	Foyaite...............	Magnet Cove, Ark......................	J. G., IX, 611.—W. T.

SUBRANG 4. MIASKOSE.

(I. 6, 1, 4.)

60.02	0.202	Phonolite	Cripple Creek, Colo....................	Bull. 168, 143.—W. T.
59.38	.189	Trachytic phonolite..	.....do	Bull. 168, 144.—W. T.
59.00	.196	Phonolite	.....do	Bull. 168, 143.—W. T.
58.98	.219	.....do	.....do	Do.
58.78	.213	.....do	.....do	Do.
58.77	.211 (59.1)	Foyaite...............	Salem Neck, Mass......................	J. G., VII, 481.—W. T.
58.74	.205	Nephelite-syenite	Salina County, Ark.....................	I. R. A., 139.—W. T.
58.70	.190	Acmite-trachyte......	Crazy Mountains, Mont	Bull. 168, 123.—W. T.
58.64	.195 (.196)	Phonolite	Cripple Creek, Colo....................	Bull. 168, 143.—W. T.
58.62	.191 (58.5-.186)	.....do	Nosy Komba, Madagascar............	M. M., 169.
58.61	.194 (58.3)	Foyaite...............	Heum, Lougenthal, Norway	E. K., III, 377.—W. T.
58.61	.213 (58.5)	.....do	Nosy Komba, Madagascar............	M. M., 169.
58.51	.216 (58.2)	Phonolite	Velay, France...........................	R. T., 1879, LVIII.
58.25	.197 (57.7)	Microfoyaite	Nosy Komba, Madagascar............	M. M., 169.
58.20	.190	Ditroite...............	.....do	Do.
58.10	.191 (57.9)	.....do	.....do	M. M., 204.
57.86	.214 (57.8)	Phonolite	Black Hills, S. Dak....................	Bull. 168, 84.—W. T.
56.75	.228	Tinguaite	Pickards Point, Mass..................	J. G., VII, 481.—W. T.
56.67	.226 (56.3)	Nephelite-syenite	Picota, Portugal.......................	T. M. P. M., XVI, 228.—W. T.
56.43	.195 (56.3)	Phonolite	Hegau, Germany.......................	R. T., 1884, LIV.
56.40	.201	Nephelite-syenite	Poutelitschorr, Kola, Finland........	Rosenbusch, El., 126.—W. T.
56.30	.235	Ditroite	Ditro, Siebenbürgen, Hungary.......	Rosenbusch, El., 126.
56.26	.199 (56.8)	Miascite..............	Mount Sobatchia, Siberia	W. T.
55.95	.256	Phonolite	Borczen, Bilin..........................	R. T., 1869, XCVI.
55.93	.203 (55.6)	Trachytic phonolite..	Columbretes Islands...................	T. M. P. M., XVI, 314.—W. T.
55.92	.198 (55.8)	Phonolite	Hegau, Germany.......................	R. T., 1884, LII.
55.21	.226	.....do	.....do	R. T., 1879, LVIII.
55.01	.211	.....do	.....do	R. T., 1884, LII.
54.92	.243	Nephelite-aplite......	Cabo Frio Island, Brazil...............	T. M. P. M., XX, 288.—W. T.
54.22	.224	Phonolite	Southboro, Mass.......................	Bull. 168, 33.—W. T.
54.20	.237	Nephelite-syenite	Picota, Portugal.......................	T. M. P. M., XVI, 218.—W. T.
53.95	.246	Phonolite	Sardinia.................................	R. T., 1879, LVIII.
53.65	.231	.....do	Msid Gharian, Tripoli..................	R. T., 1884, LIV.
52.73	.202	Heronite	Heron Bay, Canada	J. G., VII, 435.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 5. MARIUPOLOSE.

(I. 6, 1, 5.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
60.29	0.197 (60.5)	Mariupolite	Nikolajew, Russia	T. M. P. M., XXI, 244.—W. T.

RANG 2. VIEZZENASE.

SUBRANG 3. ——.

(I. 6, 2, 3.)

53.76	0.207 (53.6)	Nephelite-tinguaite	Magnet Cove, Ark	I. R. A., 266.—W. T.

SUBRANG 4. VIEZZENOSE.

(I. 6, 2, 4.)

56.04	0.201	Nephlite-rhomben-porphyry.	Vasvik tunnel, Norway	Z. K., XVI, 88.—W. T.
55.40	.184	Andesite	Palma, Sicily	R. T., 1879, LXVI.
54.68	.176	Nephelite-syenite	Brookville, N. J	Bull. 168, 89.—W. T.
54.61	.197	do	Caldas de Monchique, Portugal	N. J., B. B., III, 271.—W. T.
54.46	.186	Tinguaite	Umptek, Kola, Finland	Rosenbusch, El., 215.—W. T.

ORDER 7. TASMANARE.

RANG 1. LAUGENASE.

SUBRANG 4. LAUGENOSE.

(I. 7, 1, 4.)

55.50	0.248	Foyaite	Brathagen, Norway	E. K., III, 176.—W. T.

CLASS II. DOSALANE.

ORDER 3. HISPANARE.

RANG 1. VARINGASE.

SUBRANG 3. VARINGOSE.

(II. 3, 1, 3.)

74.35	0.092	Grorudite	Varingskollen, Norway	Z. K., XVI, 66.—W. T.
70.30	.128	Pantellerite	Pantellaria	Z. K., VIII, 173.—W. T.

SUBRANG 4. ——.

(II. 3, 1, 4.)

72.12	0.070	Felsite	Cudgegong River, New South Wales, Australia.	W. T.

Classified list of analyses used in constructing diagrams—Continued.

Rang 4. ———.

Subrang 3. ———.

(II. 3, 4, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.88	0.020	Quartz-diorite	Little Falls, Minn	R. T., 1879, XXXVI.

Order 4. Austrare.

Rang 1. Pantellerase.

Subrang 3. Grorudose.

(II. 4, 1, 3.)

70.15	0.109	Grorudite	Grusletten, Norway	E. K., I, 199.—W. T.
69.61	.129	Pantellerite	Pantellaria	Z. K., VIII, 173.—W. T.
69.02	.121	do	do	Z. K., VIII, 182.—W. T.
68.33	.137	do	do	Z. K., VIII, 170.—W. T.
66.50	.123	Grorudite	Grusletten, Norway	E. K., I, 199.—W. T.
61.88	.102 (62.2)	Porphyrite	Süpplingen, Magdeburg, Prussia	W. T.

Subrang 4. Pantellerose.

(II. 4, 1, 4.)

71.85	0.116	Grorudite	Kallerud, Norway	E. K., I, 199.—W. T.
67.89	.116	Pantellerite	Pantellaria	Z. K., VIII, 186.—W. T.
67.48	.131	do	do	Do.
67.18	.122	do	do	Do.

Rang 2. Dacase.

Subrang 3. Adamellose.

(II. 4, 2, 3.)

66.57	0.103	Granite-porphyry	Kirche Wang, Silesia	Rosenbusch, El., 195.
63.97	.105	Quartz-mica-diorite	Crandall Basin, Wyo	Bull. 168, 94.—W. T.
62.51	.090	Syenite	Reichenstein, Silesia	N. J., 1890, I, 206.—W. T.
61.93	.104	Granitite	Laveline, Vosges	Rosenbusch, El., 78.
59.24	.095 (59.5)	Trachyte-andesite	Highwood Mountains, Mont	Bull. 168, 131.—W. T.

Subrang 4. Dacose.

(II. 4, 2, 4.)

65.50	0.107	Andesite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 91.—W. T.
64.47	.098	Granitite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
63.50	.101	Dacite	Chiles, Colombia, South America	J. G., I, 171.—W. T.
61.56	.102	Andesite	Tower Creek, Yellowstone Park	Bull. 168, 108.—W. T.
56.59	.083	Quartz-diorite	Sauk Center, Minn	R. T., 1879, XXXIV.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. TONALASE.

SUBRANG 3. HARZOSE.

(II. 4, 3, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
64.34	0.081	Granite	Butte, Mont	Bull. 168, 117.—W. T.
63.85	.080	Granodiorite	Grass Valley, Cal	Bull. 168, 194.—W. T.
63.06	.069 (63.2)	"Schliere" in granite.	Riesengebirge, Silesia	N. J., 1898, XII, 236.—W. T.
61.73	.088	Syenite	Hodritch, Hungary	R. T., 1869, LX.
61.64	.078	Quartz-monzonite	Red Rock Creek, Butte, Mont	Bull. 168, 118.—W. T.
60.68	.090 (60.7)	Andesite	Mount Pagos, Asia Minor	A. J. S. III, 1897, 43.—W. T.
60.17	.090	Latite	Tintic district, Utah	Bull. 168, 166.—W. T.
59.76	.094	Monzonite	do	Do.
57.80	.063	Quartz-pyroxene-diorite.	Sonora, Tuolumne County, Cal	Bull. 168, 204.—W. T.
57.69	.064 (58.1)	Mica-diorite	Gippsland, Victoria	E. K., II, 37.—W. T.
57.26	.076	Quartz-mica-diorite	Sierra County, Cal	Bull. 168, 192.—W. T.

SUBRANG 4. TONALOSE.

(II. 4, 3, 4.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
66.91	0.055	Tonalite	Adamello Stock, Tyrol	Rosenbusch, El., 140.—W. T.
65.83	.080	Granite	Granite Creek Station, Nev	Fortieth Par., I, 110.
65.39	.081	Dacite	Cumbal, Colombia, South America	J. G., I, 171.—W. T.
65.11	.083	Quartz-mica-diorite	Electric Peak, Yellowstone Park	Bull. 168, 88.—W. T.
64.81	.073	Porphyrite	Leadville district, Colo	Bull. 168, 155.—W. T.
64.12	.077 (.076)	Quartz-norite	Tyrol	Rosenbusch, El., 140.
64.07	.083	Quartz-mica-diorite	Electric Peak, Yellowstone Park	Bull. 168, 87.—W. T.
63.56	.084	Hornblende-dacite	Colombia, South America	J. G., I, 171.—W. T.
63.47	.075	Andesite	Suppans Mountain, Tehama County, Cal.	Bull. 168, 182.—W. T.
63.28	.077	do	Mount Hood, Oreg	Fortieth Par., I, 604.
63.16	.089	Trachyte	Henry Mountains, Utah	Bull. 168, 167.—W. T.
63.03	.070	Andesite	Mount Shasta, Cal	Bull. 168, 176.—W. T.
62.71	.084	Diorite	Gunnison County, Colo	Bull. 168, 159.—W. T.
62.65	.095	Hornblende-porphyrite.	Herman Peak, Colo	Bull. 168, 164.—W. T.
62.62	.070	Quartz-mica-diorite	Mariposa County, Cal	Bull. 168, 209.—W. T.
62.44	.071	Andesite	Shasta County, Cal	Bull. 168, 181.—W. T.
62.09	.070	Hornblende-porphyrite.	Nevada City, Cal	Bull. 168, 194.—W. T.
61.58	.074 (61.8)	Andesite	Mount Shasta, Cal	Bull. 168, 176.—W. T.
61.40	.048	Syenite	Riesengebirge, Silesia	N. J., 1898, XII, 234.—W. T.
61.22	.089 (61.4)	Mica-diorite	Electric Peak, Yellowstone Park	Bull. 168, 87.—W. T.
61.17	.077	Andesite	Shasta County, Cal	Bull. 168, 183.—W. T.
61.16	.093	Andesite-porphyry	Crandall Basin, Wyo	Bull. 168, 94.—W. T.
61.09	.070	Andesite	Colombia, South America	J. G., I, 171.—W. T.
61.04	.090	do	do	Do.
60.93	.073	do	Tuscan Buttes, Cal	Bull. 168, 181.—W. T.
60.30	.088 (60.4)	do	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.
60.20	.068	do	Pilot Peak, Plumas County, Cal	Bull. 168, 188.—W. T.
60.05	.079	do	Colombia, South America	J. G., I, 171.—W. T.
60.04	.078 (60.3)	do	Shasta County, Cal	Bull. 168, 181.—W. T.
60.02	.074 (59.8)	do	Sierra County, Cal	Bull. 168, 198.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

Subrang 4. Tonalose—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
59.97	.076	Diorite	Vildarthal, Tyrol	Rosenbusch, El., 140.
59.84	.080	Andesite	Near Lassen Peak, Cal	Bull. 168, 183.—W. T.
59.77	.088	Average of 680 igneous rocks.	America	Bull. 148, 12.—W. T.
59.48	.082	Andesite	Red Bluff, Mont	Bull. 168, 114.—W. T.
59.34	.075	do	Sierra County, Cal	Bull. 168, 193.—W. T.
59.19	.094	Diorite	San Miguel Mountains, Colo	Bull. 168, 164.—W. T.
58.67	.065	Dolerite	Eskdale, Scotland	
58.63	.079 (58.9)	Diorite	Unalaska Island	Bull. 168, 226.—W. T.
58.46	.083 (58.7)	Average of 397 igneous rocks.	Great Britain	Geol. Mag., 1899, 220.—W. T.
58.08	.075 (58.2)	Andesite	Near Lassen Peak, Tehama County, Cal.	Bull. 168, 182.—W. T.
56.61	.082	do	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.
56.28	.065	Diorite	Electric Peak, Yellowstone Park	Bull. 168, 87.—W. T.
55.83	.069 (55.9)	Andesite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.

Subrang 5. Placerose.

(II. 4, 3, 5.)

64.67	0.064	Granite	Placer County, Cal	Bull. 168, 198.—W. T.
60.40	.068	Andesite	St. Augustine Volcano, Cook Inlet	Bull. 168, 226.—W. T.

Rang 4. Bandase.

Subrang 1. Sagamose.

(II. 4, 4, 1.)

55.48	0.023	Tonalite	Hokizawa, Sagami, Japan	W. T.

Subrang 3. Bandose.

(II. 4, 4, 3.)

61.58	0.057	Diorite	Kadiak Island, Alaska	Bull. 168, 227.—W. T.
59.66	.052	Andesite	Bandai San, Japan	W. T.
56.74	.047	Diabase-porphyry	Mount Morrison, Colo	Bull. 168, 141.—W. T.
56.51	.068 (56.7-.066)	Quartz-basalt	Near Lassen Peak, Cal	Bull. 168, 185.—W. T.
56.41	.052	Diorite	Georgetown, D. C	Bull. 168, 44.—W. T.
56.31	.044	"Schliere" in granite	Riesengebirge, Silesia	N. J., 1898, XII, 235.—W. T.
55.97	.052	Diorite	Triadelphia, Md	Bull. 168, 44.—W. T.

Rang 5. ———.

Subrang 3. ———.

(II. 4, 5, 3.)

51.62	0.015	Diorite	Kagelholmsön, Sweden	R. T., 1879, XXXII.

Classified list of analyses used in constructing diagrams—Continued.

Order 5. Germanare.

Rang 1. Umptekase.

Subrang 2. Highwoodose.

(II. 5, 1, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
61.28	0.126	Syenite	Tuolumne County, Cal	Bull. 168, 204.—W. T.
58.04	.166	Trachyte	Highwood Mountains, Mont	Bull. 168, 131.—W. T.

Subrang 3. Ilmenose.

(II. 5, 1, 3.)

62.99	0.139	Umptekite	Beverly, Mass	T. M. P. M., XX, 248.—W. T.
57.91	.181	Sodalite-trachyte	Monte Santo, Naples, Italy	A. J. S., VIII, 1899, 290.—W. T.
55.26	.171	Leucite-trachyte	Viterbo, Italy	J. G., V, 370.—W. T.

Subrang 4. Umptekose.

(II. 5, 1, 4.)

64.28	0.156	Sölvsbergite	Andrews Point, Mass	J. G., VII, 481.—W. T.
63.71	.152	Umptekite	Kola, Finland	Rosenbusch, El., 112.—W. T.
62.70	.162	Sölvsbergite	Laugendal, Norway	E. K., I, 199.—W. T.
60.50	.159	Hedrumite	Ostö, Norway	E. K., III, 377.—W. T.
59.66	.180	Nephelite-syenite	Crazy Mountains, Mont	Bull. 168, 123.—W. T.
59.01	.171	.....do	Red Hill, N. H	Bull. 168, 23.—W. T.
58.90	.181	Nephelite-sölvsbergite.	Aklungen, Norway	E. K., I, 199.—W. T.
58.81	.163	Soda-syenite	Laupstadeid, Norway	B. M. A., 1898, VII, 48.—W. T.
58.46	.162	Nordmarkite	Cabo Frio, Brazil	T. M. P. M., XX, 244.—W. T.
57.52	.172	Hedrumite	Brathagan, Norway	E. K., III, 190.—W. T.
57.00	.170	Heumite	.....do	E. K., III, 116.—W. T.

Rang 2. Monzonase.

Subrang 2. Ciminose.

(II. 5, 2, 2.)

56.39	0.110 (56.6)	Mica-trachyte	Monte Catini, Italy	A. J. S., IX, 1900, 47.—W. T.
55.85	.157	Leucite-phonolite	Bolsena, Italy	J. G., V, 370.—W. T.
55.46	.107	Ciminite	Monte Cimino, Italy	A. J. S., IX, 1900, 44.—W. T.
52.21	.151	Leucite-trachyte	Viterbo, Italy	J. G., V, 370.—W. T.
51.05	.125	Durbachite	Schwarzwald, Baden	W. T.

Subrang 3. Monzonose.

(II. 5, 2, 3.)

61.65	0.113	Syenite	Yogo Peak, Little Belt Mountains, Mont.	Bull. 168, 125.—W. T.
60.56	.127	Granite	Elliott County, Ky	Bull. 168, 56.—W. T.
59.78	.140	Syenite	Custer County, Colo	Bull. 168, 151.—W. T.
58.18	.134	Kersantite	Tito, Chile	Z. D. G. G., LI, 4.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. MONZONOSE—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
58.00	0.142	Pulaskite	Laugenthal, Norway	E. K., III, 375.—W. T.
57.97	.116	Diorite	Mount Ascutney, Vermont	Bull. 168, 25.—W. T.
57.73	.147	Trachyte	Ischia, Italy	R. T., 1873, XXXVIII.
57.48	.118	Andesite	Pikes Peak district, Colo	Bull. 168, 145.—W. T.
57.29	.134	Quartz-banakite	Head of Ishawooa River, Wyo	Bull. 168, 102.—W. T.
56.75	.149	Ciminite	Arso, Ischia, Italy	A. J. S., VIII, 1899, 290.—W. T.
55.35	.100	Mica-basalt	Santa Maria Basin, Arizona	Bull. 168, 173.—W. T.
55.23	.143	Trachyte	Highwood Mountains, Mont	Bull. 168, 131.—W. T.
54.86	.114	Shoshonite	Indian Peak, Wyo	Bull. 168, 100.—W. T.
54.42	.109 (54.0)	Monzonite	Yogo Peak, Mont	Bull. 168, 128.—W. T.
54.20	.106	.....do	Monzoni, Tyrol	E. K., II, 24.—W. T.
52.81	.124 (52.6)	.....do	Bearpaw Mountains, Mont	Bull. 168, 135.—W. T.
52.80	.150	Shonkinite-monzonite	Maros, Celebes	G. C., 25.
52.63	.133	Banakite	Hoodoo Mountain, Wyo	Bull. 168, 101.—W. T.
52.33	.147	.....do	Head of Ishawooa River, Wyo	Do.
52.14	.116	Syenite	Heidelberg, Baden	R. T., 1879, XXIV.
51.82	.134	Banakite	Head of Lamar River, Yellowstone Park.	Bull. 168, 101.—W. T.
51.46	.131	.....do	Ishawooa Canyon, Wyo	Do.

SUBRANG 4. AKEROSE.

(II. 5, 2, 4.)

61.87	0.119	Syenite	Castle Mountain district, Mont	Bull. 168, 130.—W. T.
61.63	.125	Nephelite-syenite	Mulatto, Tyrol	K. A. W. W., CXI, 1, 260.
61.26	.104	Andesite	Colombia, South America	J. G., I, 171.—W. T.
61.06	.114	Porphyrite	Crazy Mountains, Mont	Bull. 168, 120.—W. T.
60.44	.110	Diorite-porphyry	La Plata Mountains, Colo	Bull. 168, 162.—W. T.
59.56	.125	Akerite	Vettakollen, Norway	Z. K., XVI, 50.—W. T.
58.28	.155	Syenite	Crazy Mountains, Mont	Bull. 168, 121.—W. T.
57.01	.124	Andesite	Silver Cliff, Colo	Bull. 168, 148.—W. T.
56.79	.118	Akerite	Vettakollen, Norway	Z. K., XVI, 50.—W. T.
56.75	.108	Porphyrite	Crazy Mountains, Mont	Bull. 168, 121.—W. T.
56.02	.119	Andesite	Taal, Luzon, P. I	N. J., B. B., I, 1881, 482.
55.95	.135	Ditroite	Nosy Komba, Madagascar	M. M., 204.
55.53	.115	Diorite	La Plata Mountains, Colo	Bull. 168, 162.—W. T.
54.69	.136 (54.6)	Porphyrite	Crazy Mountains, Mont	Bull. 168, 121.—W. T.
53.80	.144	Diorite	Silver Cliff, Colo	Bull. 168, 147.—W. T.
53.60	.124	Basalt	Reinhardswald, Prussia	W. T.
53.15	.129	Essexite	Shefford Mountain, Quebec	J. G., XI, 265.
53.12	.171	Tephritic-trachyte	Columbretes Islands	T. M. P. M., XVI, 314.—W. T.
51.42	.130 (51.3)	Basalt	S. Rhone	R. T., 1879, LXXII.
51.22	.162	Minette	Brathagen, Norway	E. K., III, 376.—W T

RANG 3. ANDASE.

SUBRANG 2. ——.

(II. 5, 3, 2.)

57.31	0.094	Ciminite	Monte Cimino, Italy	A. J. S., IX, 1900, 44.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. SHOSHONOSE.

(II. 5, 3, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
59.41	0.102	Andesite	Cabo da Gata, Spain	Z. D., g. G., XLIII, 719.—W. T.
58.51	.095 (58.8)	Mica-diorite	Crystals Falls, Mich	Bull. 168, 67.—W. T.
57.97	.083 (57.8)	Diorite	Crazy Mountains, Mont	Bull. 168, 122.—W. T.
56.90	.097	Syenite	Denver Basin, Colo	Bull. 168, 140.—W. T.
56.78	.093	Latite	Clover Meadow, Cal	Bull. 168. 205.—W. T.
56.19	.092	.....do	Table Mountain, Tuolumne County, Cal.	Bull. 168, 205.—W. T.
56.05	.107	Shoshonite	Two Ocean Pass, Yellowstone Park	Bull. 168, 100.—W. T.
55.69	.100 (55.6)	Vulsinite	Rocca Monfina, Italy	J. G., V, 358.—W. T.
54.56	.076 (.075)	Andesite	Radicofani, Italy	A. J. S., IX, 1900, 52.—W. T.
54.14	.077	.....do	.....do	Do.
53.49	.104	Shoshonite	Beaverdam Creek, Yellowstone Park.	Bull. 168, 100.—W. T.
52.93	.132	Banakite	.....do	Bull. 168, 102.—W. T.
52.59	.099 (52.7)	Basalt	Table Mountain, Colo	Bull. 168, 140.—W. T.
52.49	.102	Shoshonite	Pyramid Peak, Yellowstone Park	Bull. 168, 100.—W. T.
52.33	.103	Augite-porphyy	Cottonwood Creek, Mont	Bull. 168, 112.—W. T.
52.11	.097 (51.8)	Basalt	Crandall Basin, Wyo	Bull. 168, 92.—W. T.
51.00	.115	Monzonite	Highwood Mountains, Mont	Bull. 168, 133.—W. T.
50.98	.120 (50.7)	Mondhaldeite	Mondhalde, Kaiserstuhl, Baden	W. T.
50.08	.137	.....do	.....do	Do.
50.06	.110	Shoshonite	Lamar River, Yellowstone Park	Bull. 168, 100.—W. T.
49.69	.107	Basalt	Denver Basin, Colo	Bull. 168, 140.—W. T.
48.25	.118	Dolerite	.....do	Do.
47.50	.117	Labrador-porphyrite.	Gran, Norway	Q. J. G. S., L, 33.—W. T.
45.53	.140	Leucite-monchiquite.	Bohemian Mittelgebirge	Rosenbusch, El., 235.—W. T.

SUBRANG 4. ANDOSE.

(II. 5, 3, 4.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
58.45	0.080	Diorite	Pen Maen Mawr, N. Wales	Q. J. G. S., XXXIII, 424.
58.42	.099	Andesite	Taal, Luzon, P. I	N. J., B. B., I, 1881, 481.
58.05	.083	Diorite	Electric Peak, Yellowstone Park	Bull. 168, 87.—W. T.
57.64	.104 (57.8)	Augite-porphyrite	Crandall Basin, Wyo	Bull. 168, 93.—W. T.
57.59	.070 (57.8)	Quartz-basalt	Silver Lake, Lassen, Cal	Bull. 168, 185.—W. T.
57.38	.071 (57.1)	Pyroxene porphyry	Electric Peak, Yellowstone Park	Bull. 168, 87.—W. T.
57.32	.098 (57.5)	Monzonite	Crandall Basin, Wyo	Bull. 168, 93.—W. T.
57.26	.102	Diorite	.....do	Do.
57.25	.067	Quartz-basalt	Cinder Cone, Lassen, Cal	Bull. 168, 184.—W. T.
57.17	.079	Andesite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.
57.11	.084 (57.5)	.....do	Mill Creek, Lassen, Cal	Bull. 168, 182.—W. T.
56.91	.085	.....do	Colombia, South America	J. G., I, 171.—W. T.
56.70	.074 (56.6)	Quartz-basalt	Cinder Cone, Lassen, Cal	J. G., I, 184.—W. T.
56.49	.112 (57.1)	Diorite	Little Falls, Minn	R. T., 1879, XXXIV.
56.21	.104	Gabbro-diorite	Crandall Basin, Wyo	Bull. 168, 93.—W. T.
56.19	.076	Andesite	Buffalo Peaks, Colo	Bull. 168, 153.—W. T.
56.09	.080	Diorite	Campo Major, Portugal	E. K., II, 37.—W. T.
56.07	.091 (55.9)	Andesite	Bogoslof Island	Bull. 168, 227.—W. T.
55.93	.103 (55.8)	Gabbro-diorite	Crandall Basin, Wyo	Bull. 168, 93.—W. T.
55.92	.095	Andesite	Sepulchre Mountain, Yellowstone Park.	Bull. 168, 90.—W. T.
55.80	.076	Diorite (norite)	Klausen, Tyrol	E. K., II, 37.—W. T.
55.34	.093	Norite	Montrose Point, N. Y	W. T.

Classified list of analyses used in constructing diagrams—Continued.

Subrang 4. Andose—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
55.20	0.075 (55.4)	Andesite	Butte County, Cal	Bull. 168, 182.—W. T.
55.13	.107	Diorite	Neihart, Mont	Bull. 168, 127.—W. T.
54.62	.075	Andesite	Luzon, P. I	N. J., B. B., I, 1881, 471.
54.56	.108	Diorite-porphyrite	Crazy Mountains, Mont	Bull. 168, 121.—W. T.
54.52	.092	Diabase	Diabase Hills, Nev	Fortieth Par., II, 812.
53.94	.086	Dolerite	do	Do.
53.89	.099	Basic andesitic glass	Indian Ridge, Wyo	Bull. 168, 92.—W. T.
53.71	.098	Mica-gabbro	Crandall Basin, Wyo	Do.
53.48	.089	Quartz-diorite	Crazy Mountains, Mont	Bull. 168, 121.—W. T.
53.10	.134 (53.2)	Covite	Nosey Komba, Madagascar	M. M., 204.
52.97	.107	Basalt	Pikes Peak district, Colo	Bull. 168, 145.—W. T.
52.91	.119	Diabase-syenite-porphyry.	Holmestrand, Norway	Z. K., XVI, 28.—W. T.
52.63	.082 (52.7)	Basalt	Shasta County, Cal	Bull. 168, 186.—W. T.
52.38	.093	do	Rio Grande, N. Mex	Bull. 168, 169.—W. T.
52.37	.084	do	Absaroka Range, Yellowstone Park	Bull. 168, 109.—W. T.
52.37	.082 (51.8)	do	Rio Grande, N. Mex	Bull. 168, 169.—W. T.
52.27	.095	do	do	Do.
52.12	.095	Diorite	Mount Ascutney, Vt	Bull. 168, 25.—W. T.
52.09	.085	Basalt	Crandall Basin, Wyo	Bull. 168, 92.—W. T.
51.57	.090	do	Rio Grande, N. Mex	Bull. 168, 169.—W. T.
51.54	.110	Andesite	Bogoslof Island, Alaska	Bull. 168, 227.—W. T.
50.99	.101	Camptonite	Ishawooa Canyon, Wyo	Bull. 168, 110.—W. T.
50.97	.112 (50.6)	Kersantite	Guanta, Chile	Z. D. g. G., LI, 4.
50.73	.099	Diorite	Crazy Mountains, Mont	Bull. 168, 122.—W. T.
50.56	.079	Basalt	Plumas County, Cal	Bull. 163, 189.—W. T.
49.40	.087	Facies of monzonite	Predazzo, Tyrol	E. K., II, 102.—W. T.
49.24	.092 (49.7)	Dolerite	Ferdinandea	T. M. P. M., 1883, 393.
49.04	.110	Basalt	Buffalo Peak, Colo	Fortieth Par., I, 676.
48.90	.090	Diorite	Schwarzenberg, Vosges	Rosenbusch, El., 140.
48.85	.131	Essexite	Mount Johnson, Quebec	J. G., XI, 265.
48.76	.105	Basalt	Pikes Peak district, Colo	Bull. 168, 145.—W. T.
48.18	.093	Olivine-diabase	Biella, Piedmont	R. T., 1884, XLII.
48.06	.084	Kersantite	Laugendal, Norway	E. K., III, 376.—W. T.
44.85	.110	Nephelite-tephrite	Mittelgebirge, Bohemia	Rosenbusch, El., 346.—W. T.

Subrang 5. Beerbachose.

(II. 5, 3, 5.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
55.08	0.081	Andesite-basalt	Shasta County, Cal	Bull. 168, 176.—W. T.
52.58	.073	Andesite	S. W. Tiflis	Z. D. g. G., XXIX, 823.
47.21	.109	Beerbachite	Odenwald, Hesse	Rosenbusch, El., 219.—W. T.

Rang 4. Hessase.

Subrang 3. Hessose.

(II. 5, 4, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
57.47	0.072	Basalt	Cascade Range, Oreg	Bull. 168, 223.—W. T.
56.94	.074	Anorthosite	Elizabethtown, N. Y	Bull. 168, 37.—W. T.
55.53	.062	Andesite	Plumas County, Cal	Bull. 168, 181.—W. T.
55.14	.075	Secretion in dacite	Lassen Peak, Cal	Bull. 168, 179.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 4. HESSASE—Continued.

SUBRANG 3. HESSOSE—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
53.91	0.066	Dolerite	Plumas County, Cal	Bull. 168, 189.—W. T.
53.35	.063	Secretion in dacite	Lassen Peak, Cal	Bull. 168, 180.—W. T.
53.18	.082	Anorthosite.	Whiteface Mountain, Adirondacks, N. Y.	Bull. 168, 36.—W. T.
53.00	.070	Diorite	Schwarzenburg, Vosges	Rosenbusch, El., 140.
52.95	.073 (52.7)	Basalt	Shasta County, Cal	Bull. 168, 186.—W. T.
52.16	.074	Monzonite	Predazzo, Tyrol	E. K., II, 25.—W. T.
52.05	.075 (51.7)	Diorite	Ouray County, Colo	Bull. 168, 161.—W. T.
51.27	.064	.....do	Little Falls, Minn	R. T., 1879, XXXIV.
49.93	.074	Dolerite	Paterno, Etna, Sicily	R. T., 1884, LXXX.
49.88	.057	Olivine-gabbro	Pigeon Point, Minn	Bull. 168, 76.—W. T.
49.80	.049	Gabbro	Crystal Falls, Mich	Bull. 168, 67.—W. T.
49.15	.095	.....do	Duluth, Minn	Rosenbusch, El., 151.
48.29	.039	Gabbro-diorite	Minnesota Falls, Minn	Bull. 168, 83.—W. T.
47.94	.060 (47.5)	Basalt	Shasta County, Cal	Bull. 168, 176.—W. T.
47.88	.065	Gabbro	Elizabethtown, N. Y	Bull. 168, 37.—W. T.
46.71	.086	Olivine-gabbro	Langenlois, Austria	R. T., 1879, XXXVIII.
46.45	.047	.....do	Minnesota	Bull. 168, 82.—W. T.
45.20	.071	Diorite	Tuc d'Ess, Pyrenees	C. G. I., VIII, 1901, 882.—W. T.
44.72	.047	Corsite	Poudière, Auvergne	R. T., 1879, XXXVI.
43.42	.044	Gabbro-diorite	Ilchester, Md	Bull. 168, 44.—W. T.
43.19	.094	Basalt	Westphalia	R. T., 1879, LXXIV.

RANG 5. CORSASE.

(II. 5, 5.)

44.04	0.027	Diorite	Stone Run, Md	Bull. 168, 45.—W. T.
43.41	.020	Olivine-gabbro	Tuolumne County, Cal	Bull. 168, 206.—W. T.

ORDER 6. NORGARE.

RANG 1. LAURDALASE.

SUBRANG 2. FERGUSOSE.

(II. 6, 1, 2.)

51.75	0.147	Pseudoleucite-syenite	Highwood Mountains, Mont	Bull. 168, 133.—W. T.

SUBRANG 3. JUDITHOSE.

(II. 6, 1, 3.)

57.63	0.198	Tinguaite	Judith Mountains, Mont	A. J. S., II, 1896, 192.—W. T.
57.46	.196 (57.3)	.....do	Bearpaw Mountains, Mont	Bull. 168, 136.—W. T.
53.09	.226 (53.2)	Foyaite	Magnet Cove, Ark	J. G., IX, 611.—W. T.
52.91	.224	Leucite-tinguaite	.....do	I. R. A., 287.—W. T.
51.94	.157	Trachyte	Highwood Mountains, Mont	Bull. 168, 131.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

Subrang 4. Laurdalose.

(II. 6, 1, 4.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
59.88	0.188	Hedrumite	Hedrum, Norway	E. K., III, 377.—W. T.
56.58	.242	Tinguaite	do	E. K., I, 199.—W. T.
56.35	.211	Laurdalite	Farris, Norway	E. K., III, 375.—W. T.
55.90	.209	Tinguaite	Foya, Portugal	T. M. P. M., XVI, 262.—W. T.
55.65	.225	do	Hedrum, Norway	E. K., I, 199.—W. T.
55.18	.182	Syenite	do	E. K., III, 375.—W. T.
54.55	.192	Laurdalite	Lougendal, Norway	Do.
54.04	.283	Leucite-tinguaite	Magnet Cove, Ark	I. R. A., 287.—W. T.
53.81	.192	Syenite-pegmatite	Stoksund, Norway	Z. K., XVI, 116.—W. T.
53.73	.214	Nephelite-syenite	Transvaal	Rosenbusch, El., 126.—W. T.
51.95	.155 (51.6)	Soda-minette	Langesundsfjord, Norway	E. K., II, 376.—W. T.
50.96	.229	Leucite-nephelite-syenite.	Magnet Cove, Ark	I. R. A., 276.—W. T.
47.61	.190	Tinguaite	Two Buttes, Colo	Bull. 168, 165.—W. T.
45.16	.195	Olivine-laurdalite	Farris, Norway	E. K., III, 375.—W. T.

Rang 2. Essexase.

Subrang 3. Borolanose.

(II. 6, 2, 3.)

52.05	0.132	Monzonite	Highwood Mountains, Mont	Bull. 168, 133.—W. T.
51.35	.165	Nephelite-felsite	Magnet Cove, Ark	I. R. A., 263.—W. T.
50.24	.153 (49.9-.154)	Leucite-tephrite	Bolsena, Italy	J. G., IV, 561.—W. T.
50.15	.142 (49.8)	Shonkinite	Maros, Celebes	G. C., 24.
49.70	.167	Covite	Magnet Cove, Ark	J. G., IX, 612.—W. T.
47.8	.204	Borolanite	Lake Borolan, Scotland	Rosenbusch, El., 126.—W. T.

Subrang 4. Essexose.

(II. 6, 2, 4.)

55.07	0.162	Rhombenporphyry	Stoksund, Norway	Z. K., XVI, 116.—W. T.
54.34	.173	Nephelite-syenite	Cripple Creek, Colo	Bull. 168, 144.—W. T.
51.90	.210	Laurdalite	Lunde, Norway	E. K., III, 375.—W. T.
51.10	.173	Covite	Nosy Komba, Madagascar	M. M., 204.
50.50	.143	Nephelite-monzonite	Rongstock, Bohemia	T. M. P. M., XIV, 98, 99.—W. T.
50.26	.210	Nephelite-syenite-porphyry.	Viezzena, Tyrol	K. A. W. W., CXI, I, 275.
49.90	.155 (49.3)	Leucite-kulaite	Kula, Asia Minor	J. G., VIII, 613.—W. T.
48.69	.151 (49.0-.150)	Olivine-essexite	Mount Johnson, Quebec	J. G., XI, 265.
48.46	.243	Heumite	Lougendal, Norway	E. K., III, 376.—W. T.
48.35	.161	Kulaite	Kula, Asia Minor	J. G., VIII, 613.—W. T.
47.94	.150 (48.3)	Essexite	Salem Neck, Mass	Rosenbusch, El., 172.—W. T.
47.67	.150 (48.0)	Theralite	Alabaugh Creek, Mont	Bull. 168, 124.—W. T.
46.48	.162	Monchiquite	Rio de Janeiro, Brazil	Rosenbusch, El., 235.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

Rang 3. Salemase.

Subrang 4. Salemose.

(II. 6, 3, 4.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
50.47	0.132	Augite-diorite	Silver Cliff, Colo.	Bull. 168, 147.—W. T.
49.95	.132	Microessexite	Nosy Kamba, Madagascar	M. M., 204.
48.50	.138	Essexite	Jangoa, Madagascar	Do.
46.40	.151	Augite-diorite	Ullernas, Norway	Z. K., XVI, 49.—W. T.
45.32	.110	Hornblende-gabbro	Salem Neck, Mass	J. G., VII, 63.—W. T.
43.66	.142	Essexite	Cabo Frio Island, Brazil	Rosenbusch, El., 172.—W. T.

Subrang 5. ———.

(II. 6, 3, 5.)

47.30	0.137	Basalt	Pedregal, Mexico	W. T.

Rang 4. ———.

Subrang 3. ———.

(II. 6, 4, 3.)

45.76	0.086	Gabbro	Rosswein, Saxony	N. J., 1893, II, 503.—W. T.
45.11	.090	Diorite	Lindenfeld, Hesse	W. T.

Order 7. Italare.

Rang 1. Lujavrase.

Subrang 3. Janeirose.

(II. 7, 1, 3.)

51.93	0.278	Leucite-tinguaite	Bearpaw Mountains, Mont	Bull. 168, 136.—W. T.

Subrang 4. Lujavrose.

(II. 7, 1, 4.)

54.14	0.238	Lujavrite	Tschasnatschorr, Finland	Rosenbusch, El., 126.—W. T.
52.25	.255	Chibinite	Umptek, Finland	Fennia, XI, 2, 132.—W. T.
51.94	.208 (51.6)	Camptonitic tinguaite	Picota, Portugal	T. M. P. M., XVI, 272.—W. T.
50.63	.271	Nephelite-porphyry	Laugendal, Norway	E. K., III, 157.—W. T.
48.86	.234	Allochetite	Allochet, Monzoni, Tyrol	A. W. W., 1902, Anz. XXI.

Rang 2. Vulturase.

Subrang 2. ———.

(II. 7, 2, 2.)

50.32	0.157	Basanite	Vesuvius	R. T., 1861, 25.
49.73	.158 (49.6)	Leucite-tephrite	Bracciano, Italy	J. G., V, 370.—W. T.
47.89	.161 (47.8)	Leucitite	do	Do.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. ——.

(II. 7, 2, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
48.03	0.167	Basanite..............	Granatello, Vesuvius.................	R. T., 1861, 25.

SUBRANG 4. VULTUROSE.

(II. 7, 2, 4.)

42.46	0.229	Haüynophyre........	Melfi, Italy...........................	Rosenbusch, El., 357.

RANG 3. ——.

SUBRANG 3. ——.

(II. 7, 3, 3.)

47.40	0.130	Leucite-tephrite......	Rocca Monfina, Italy.................	J. G., V, 370.—W. T.

ORDER 8. CAMPANARE.

RANG 1. ——.

SUBRANG 3. ——.

(II. 8, 1, 3.)

50.00	0.267	Tinguaite	Beemerville, N. J......................	Bull. Mus. Comp. Zool., XXXVIII, 1902, 276.—W. T.
46.48	268	Leucitite	Etinde Volcano, Kamerund, Africa..	W. T.

SUBRANG 5. ——.

(II. 8, 1, 5.)

47.43	0.333	Soda-sussexite........	Penikkavaara, Finland	B. C. G. F., XI, 22.—W. T.

RANG 2. VESUVASE.

SUBRANG 2. VESUVOSE.

(II. 8, 2, 2.)

47.71	0.157	Leucite-basanite	Lava of 1631, Vesuvius................	W. T.
47.65	.157	.....do	Lava of 1872, Vesuvius................	W. T.
47.53	.149	Leucitophyre.........	Vesuvius	R. T., 1884, LVI.
46.36	.160 (46.2)	.....do	.....do	R. T., 1884, LVIII.

ORDER 9. LAPPARE.

RANG 1. URTASE.

SUBRANG 3. ARKANSOSE.

(II. 9, 1, 3.)

44.40	0.252	Arkite................	Magnet Cove, Ark......................	J. G., IX, 616.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 4. URTOSE.

(II. 9, 1, 4.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
45.46	0.397	Urtite	Lujavr Urt, Kola, Finland	G. F. S. F., XVIII, 462.—W. T.
45.43	.391	.....do	.....do	Do.
45.28	.418	.....do	.....do	Rosenbusch, El., 126.—W. T.
43.02	.378	Ijolite, rich in nephelite.	Kuuosamo, Finland	B. C. G. F., XI, 17.—W. T.

CLASS III. SALFEMANE.

ORDER 3. ATLANTARE.

RANG 1. ROCKALLASE.

SUBRANG 2. ——.

(III. 3, 1, 2.)

68.75	0.144	Pantellerite	Pantellaria	Z. K., VIII, 179.—W. T.

SUBRANG 5. ROCKALLOSE.

(III. 3, 1, 5.)

73.60	0.091	Rockallite	Rockall Island, Atlantic Ocean	Geol. Mag., VI, 163.—W. T.

ORDER 4. VAALARE.

RANG 3. VAALASE.

SUBRANG 4. VAALOSE.

(III. 4, 3, 4.)

53.39	0.068	Quartz-gabbro	Harz	R. T., 1884, XXXIV.
53.35	.067 (52.8)	Basalt	Teanaway River, Kittitas County, Wash.	Bull. 168, 225.—W. T.
52.67	.047 (52.9)	Olivine-diabase	Cape Colony, Africa	N. J., 1887, V, 249.—W. T.
52.22	.048 (51.9-.051)	Olivine-disbase-porphyrite.	.....do	Do.

RANG 4. ——.

SUBRANG 3. ——.

(III. 4, 4, 3.)

56.18	0.036	Diorite	Washington, D. C	Bull. 168, 44.—W. T.
45.75	.027	Melaphyre	Holmestrand, Norway	Z. K., XVI, 27.—W. T.

RANG 5. ——.

(III. 4, 5.)

47.00	0.008	Olivine-gabbro-diabase.	Sölvsberget, Norway	Z. K., XVI, 27.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

ORDER 5. GALLARE.

RANG 1. ORENDASE.

SUBRANG 1. ORENDOSE.

(III. 5, 1, 1.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
54.17	0.160	Orendite	Leucite Hills, Wyo	Bull. 168, 86.—W. T.
54.08	.163	.....do	.....do	Do.
53.70	.160 (53.6)	Wyomingite..........	.....do	Bull. 168, 85.—W. T.

SUBRANG 2. ——.

(III. 5, 1, 2.)

50.23	0.150	Wyomingite..........	Leucite Hills, Wyo	Bull. 168, 85.—W. T.

RANG 2. KILAUASE.

SUBRANG 2. PROWERSOSE.

(III. 5, 2, 2.)

50.41	0.113	Syenitic lamprophyre	Two Buttes, Colo.....................	Bull. 168, 165.—W. T.

SUBRANG 3. LAMAROSE.

(III. 5, 2, 3.)

48.98	0.107	Shonkinite	Yogo Peak, Mont.....................	Bull. 168, 128.—W. T.
48.95	.097	Absarokite	Hoodoo Mountain, Wyo..............	Bull. 168, 99.—W. T.
47.56	.099	Mica-picrophyre......	North of Prag, Bohemia..............	R. T., 1879, XLVI.
47.32	.090 (47.5)	Leucite-absarokite ...	Sunlight Valley, Wyo	Bull. 168, 97.—W. T.

SUBRANG 4. KILAUOSE.

(III. 5, 2, 4.)

46.52	0.085 (45.2)	Basalt	Volcano Butte, Castle Mountains	Bull. 168, 180.—W. T.
43.35	.099	Augitite	Mittelgebirge, Bohemia..............	Rosenbusch, El., 363.

RANG 3. CAMPTONASE.

SUBRANG 2. ABSAROKOSE.

(III. 5, 3, 2.)

49.71	0.090	Absarokite	Cache Creek, Yellowstone Park......	Bull. 168, 99.—W. T.
19.03	.082	Leucite-basanite	Bolsena, Italy	J. G., V, 370.—W. T.
48.36	.080	Absarokite	Clark Fork, Wyo	Bull. 168, 99.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. KENTALLENOSE.

(III. 5, 3, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
52.09	0.074	Kentallenite	Glen Shira, Argyllshire, Scotland	Q. J. G. S., LVI, 537.—W. T.
51.76	.083	Absarokite	Absaroka Range, Yellowstone Park	Bull. 168, 99.—W. T.
51.65	.107	Lamprophyre	Cottonwood Canyon, Mont	Bull. 168, 112.—W. T.
50.82	.075	do	Antelope and South Boulder creeks, Mont.	Bull. 168, 113.—W. T.
50.35	.101	Olivine-monzonite	Smålingen, Sweden	E. K., II, 46.—W. T.

SUBRANG 4. CAMPTONOSE.

(III. 5, 3, 4.)

54.56	0.067	Quartz-basalt	Cinder Cone, Cal	Bull. 168, 185.—W. T.
53.56	.077	Mica-porphyry	Crandall Basin, Wyo	Bull. 168, 92 —W. T.
52.35	.067	Diorite	Little Falls, Minn	N. J., 1877, 129.
51.81	.077	Gabbro-porphyry	Crandall Basin, Wyo	Bull. 168, 92.—W. T.
51.23	.076	Diabase	Halleberg, Sweden	Rosenbusch, El., 328.
49.35	.074	Dolerite	Pantellaria	T. M. P. M., 1883, 393.
48.60	.095 (48.4)	Nephelite-basalt	Elkhead Mountains, Colo	Fortieth Par., I., 676.
48.22	.084	Camptonite	Mount Ascutney, Vt	Bull. 168, 26.—W. T.
47.91	.086	Basalt	Washoe, Nev	
47.90	.094	Essexite	Tofteholmen, Norway	E. K., II, 375.—W. T.
47.28	.083	Leucite-absarokite	Ishawooa Canyon, Wyo	Bull. 168, 99.—W. T.
47.16	.077	Gabbro	Elizabethtown, N. Y	Bull. 168, 37.—W. T.
46.74	.089	do	do	Do.
45.30	.107	Basalt	Mount Trumbull, Ariz	Bull. 168, 174.—W. T.
40.60	.078	Camptonite	Maena, Gran, Norway	E. K., III, 376.—W. T.

SUBRANG 5. ORNOSE.

(III. 5, 3, 5.)

54.14	0.074	Tachylite	Hanover	R. T., 1879, LXXIV.
46.11	.081 (.077)	Ornöite	Ornö, Sweden	G. F. S. F., XV, 108.—W. T.

RANG 4. AUVERGNASE.

SUBRANG 2. ——.

(III. 5, 4, 2.)

50.03	0.062 (49.4)	Lamprophyre	South Boulder Creek, Mont	Bull. 168, 113.—W. T.
46.86	.065	Diabase-pitchstone	Meriden, Conn	Bull. 168, 35.—W. T.

SUBRANG 3. AUVERGNOSE.

(III. 5, 4, 3.)

53.13	0.053	Diabase	Jersey City, N. J	A. J. S., IX, 1875, 187.
52.42	.046	do	Wintergreen Lake, Conn	A. J. S., IX, 1875, 189.
52.68	.057	Dolerite	Mount Holyoke, Mass	A. J. S., IX, 1875, 186.
51.78	.044	Diabase	New Haven, Conn	Do.
51.46	.057	Gabbro	Sturgeon Falls, Mich	Bull. 168, 70.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 3. AUVERGNOSE—Continued.

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
51.36	0.040	Basalt	Orange, N. J	Bull. 168, 39.—W. T.
50.89	.053	do	Lassen Peak, Cal	Bull. 168, 186.—W. T.
49.87	.062	do	Pantellaria	T. M. P. M., 1883, 393.
49.63	.055 (49.5)	Diabase	Mount Ascutney, Vt	Bull. 168, 26.—W. T.
49.18	.035	Basalt	Disko, Greenland	T. M. P. M., 1874, 120.
48.23	.034	Norite	Crystal Falls, Mich	Bull. 168, 67.—W. T.
48.04	.045	Basalt	Ovifak, Greenland	T. M. P. M., 1874, 121.
47.93	.047 (47.7)	do	Paynes Creek, Cal	Bull. 168, 186.—W. T.
47.90	.043 (47.4-.040)	Diabase	Penokee-Gogebic Range, Mich	Bull. 168, 73.—W. T.
47.54	.070 (47.8-.079)	Basalt	Grant, N. Mex	Bull. 168, 170.—W. T.
47.45	.082	Gabbro	Saleix, Pyrenees	C. G. I., VIII, 1901, 832.—W. T.
47.29	.029	Pyroxene-ariegite	Lherz, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
45.66	.049	Olivine-gabbro	Birch Lake, Minn	Bull. 168, 81.—W. T.
44.90	.033	Pyroxene-ariegite	Tuc d'Ess, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
44.97	.072	Gabbro	Elizabethtown, N. Y	Bull. 168, 37.—W. T.
44.77	.057	Basalt	Kosk Creek, Cal	Bull. 168, 186.—W. T.
43.50	.062	Hornblende-monchiquite.	Magnet Cove, Ark	Rosenbusch, El., 235.—W. T.
42.77	.063	Olivine-diabase	Campton, N. H	A. J. S. XVII, 1879, 150.
42.68	.045	Ariegite	Escourgeat, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
42.03	.053 (.055)	Fourchite	Fourche Mountain, Ark	I. R. A., 108.—W. T.

RANG 5. KEDABEKASE.

(III. 5, 5.)

48.02	0.010	Norite	McKinseys Mill, Md	Bull. 168, 45.—W. T.
47.09	.014	Ariegite	Lherz, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
44.76	.020	Hypersthene-gabbro	Wetheredville, Md	Bull. 168, 44.—W. T.
44.64	.017 (45.1)	Kedabekite	Kedabek, Russia	W. T.
44.38	.019 (43.8)	Ariegite	Lherz, Pyrenees	C. G. I., VII, 1901, 833.—W. T.
44.11	.012	Kedabekite	Kedabek, Russia	W. T.
42.32	.025	Ariegite	Lherz, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
38.95	.029	do	do	Do.

ORDER 6. PORTUGARE.

RANG 1. WYOMINGASE.

SUBRANG 3. ———.

(III. 6, 1, 3.)

50.00	0.110	Shonkinite	Bearpaw Mountains, Mont	Bull. 168, 136.—W. T.

SUBRANG 4. ———.

(III. 6, 1, 4.)

48.39	0.121 (48.5)	Analcite-basalt	Little Belt Mountains, Mont	Bull. 168, 128.—W. T.
45.72	.166	Monchiquite	Fohberges, Baden	W. T.
42.30	.157	Nephelinite	Katzenbuckel, Odenwald	Rosenbusch, El., 357.
40.03	.140 (40.2)	Camptonite	Oxford, N. J	Rosenbusch, El., 235.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

RANG 2. MONCHIQUASE.

SUBRANG 3. SHONKINOSE.

(III. 6, 2, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
49.59	0.139	Leucite-syenite	Highwood Mountains, Mont	Bull. 168, 132.—W. T.
48.05	.142 (48.5)	Shonkinite	Maros, Celebes	G. C., 23.
47.98	.136	Leucite-basalt	Highwood Mountains, Mont	Bull. 168, 132—W. T.
46.73	.088 (45.9)	Shonkinite	Square Butte, Mont	B. G. S. A., VI, 414.—W. T
45.19	.101 (44.8)	Nephelite-basalt	Breitfirst, Hesse	Rosenbusch, El., 357.
43.85	.150	Leucite-monchiquite.	Mittelgebirge, Bohemia	Rosenbusch, El., 235.—W. T.

SUBRANG 4. MONCHIQUOSE.

(III. 6, 2, 4.)

48.43	0.114	Hornblende-vogesite.	Hohwald, Elsass	Rosenbusch, El., 231.
47.82	.121	Monchiquite	Highwood Mountains, Mont	Bull. 168, 132.—W. T.
45.59	.110 (45.8)	Analcite-basalt	Pikes Peak district, Colo	Bull. 168, 146.—W. T.
45.56	.154	Nephelite-tephrite	Herrnberg, Tetschen, Bohemia	W. T.
44.54	.124	Limburgite	Heldburger Feste, S. Thüringen	Rosenbusch, El., 363.
43.84	.119	Leucite-basanite	Blankenhornberg, Kaiserstuhl, Baden	W. T.

RANG 3. LIMBURGASE.

SUBRANG 3. OUROSE.

(III. 6, 3, 3.)

46.65	0.114	Labradorite-porphyry	Wildkaar, Tyrol	R. T., 1879, XLIV.
43.74	.108	Monchiquite	Rio do Ouro, Brazil	Rosenbusch, El., 235.—W. T.
42.46	.068	do	Willow Creek, Mont	Bull. 168, 130.—W. T.

SUBRANG 4. LIMBURGOSE.

(III. 6, 3, 4.)

46.60	0.112 (46.3)	Nephelite-gabbro	Nosy Komba, Madagascar	M. M., 204.
46.35	.086	Nephelite-basanite	Römhild, S. Thüringen	Rosenbusch, El., 316.
44.82	.073 (44.5-.074)	Paleolimburgite	Atacama, Chile	Z. D. g. G., LI, 4.
43.65	.071 (43.8)	Olivine-gabbro-diabase.	Brandberget, Gran, Norway	Q. J. G. S., L, 19.—W. T.
43.50	.107	Augitite	Limberg, Baden	W. T.
41.01	.082	Hornblende-basalt	Sparbrod, Rhone	N. J., 1882, II, 155.
40.70	.084 (40.5)	Limburgite	Oberersteinberg, Lausitzer Mountains, Prussia.	Rosenbusch, El. 363.
40.10	.109 (40.4)	Ijolite	Ampasibitika, Madagascar	M. M., 204.
37.90	.095	Hornblendite	Brandberget, Gran, Norway	Q. J. G. S., L, 19.—W. T.

SUBRANG 5. ——.

(III. 6, 3, 5.)

41.94	0.121	Camptonite	Campton Falls, N. H	A. J. S., XVII, 1879, 150.

Classified list of analyses used in constructing diagrams—Continued.

RANG 4. ———.

SUBRANG 1. ———.

(III. 6, 4, 1.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
39.84	0.046 (40.4)	Hornblende-gabbro..	Piedmont, Italy........................	Rosenbusch, El., 151.

SUBRANG 3. ———.

(III. 6, 4, 3.)

45.40	0.063	Dioritic gabbro.......	Nosy Komba, Madagascar	M. M., 204.

ORDER 7. KAMERUNARE.

RANG 1. MALIGNASE.

SUBRANG 3. ———.

(III. 7, 1, 3.)

47.85	0.144	Nephelite-malignite..	Poohbah Lake, Ontario	Rosenbusch, El., 176.—W. T.

SUBRANG 4. MALIGNOSE.

(II, 7, 1, 4.)

51.88	0.180	Garnet-pyroxene-malignite.	Poohbah Lake, Ontario	Rosenbusch, El., 176.—W. T.
51.38	.193	Amphibole-malignite	.....do..................................	Do.
44.65	.186	Theralite.............	Crazy Mountains, Mont	Bull. 168, 124.—W. T.
42.02	.161 (41.8)	Ijolite-porphyry......	Alnö, Sweden	N. J., 1897, II, 99.—W. T.

RANG 2. KAMERUNASE.

SUBRANG 3. ———.

(III. 7, 2, 3.)

46.04	0.127	Leucite-basalt........	Highwood Mountains, Mont.........	Bull. 168, 132.—W. T.

SUBRANG 4. KAMERUNOSE.

(III, 7, 2, 4.)

47.10	0.178	Heumite..............	Laugendal, Norway...................	E. K., III, 376.—W. T.
46.53	.123	Theralite.............	Umptek, Finland.......................	Rosenbusch, El., 176.—W. T.
45.77	.163	Farrisite..............	Farris, Norway..........................	E. K., III, 376.—W. T.
44.31	.147	Theralite.............	Gordons Butte, Mont..................	Bull. 168, 124.—W. T.
42.77	.143 (43.0)	Monchiquite	Kiechlinsbergen, Baden..............	W. T.
42.65	.133 (43.3)	Basalt.................	Cape Verde, Africa....................	R. T., 1884, LXXIV.
40.10	.167 (40.3)	Leucite-nephelinite..	Etinde Volcano, Kamerun, Africa....	W. T.
39.97	.183 (40.2)	.....do................	.....do.................................	Do.
39.30	.165 (40.8)	Haüynophyre	.....do.................................	Do.

Classified list of analyses used in constructing diagrams—Continued.

RANG 3. ETINDASE.

SUBRANG 4. ETINDOSE.

(III, 7, 3, 4.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
40.52	0.097	Nephelite-basalt	Hesse-Darmstadt	Rosenbusch, El., 357.
39.83	.109	do	Mittelgebirge, Bohemia	Do.
38.46	.143 (38.9)	Camptonite	Mulatto, Predazzo, Tyrol	K. A. W. W., CXI, I, 234.

ORDER 8. BOHEMARE.

RANG 1. CHOTASE.

SUBRANG 2. CHOTOSE.

(III. 8, 1, 2.)

46.51	0.167	Leucitite	Bearpaw Mountains, Mont	Bull. 168, 136.—W. T.

RANG 2. ALBANASE.

SUBRANG 2. ALBANOSE.

(III. 8, 2, 2.)

47.47	0.137	Leucite-tephrite	Vesuvius, lava of 1760	R. T., 1884, LVI.
45.99	.168 (46.1)	Leucitite	Capo di Bove, Italy	A. J. S., IX, 1900, 53.—W. T.

SUBRANG 3. ——.

(III. 8, 2, 3.)

41.24	0.141	Nephelinite	Laacher See, Rhine province	Rosenbusch, El., 357.

SUBRANG 4. COVOSE.

(III. 8, 2, 4.)

43.18	0.186	Theralite	Crazy Mountains, Mont	Rosenbusch, El., 176.
42.06	.132	Limburgite	Habichtswald, Hesse	Rosenbusch, El., 363.
41.74	.204	Ijolite	Magnet Cove, Ark	J. G., IX, 618.—W. T.
40.15	.204 (40.3)	Nephelinite	Etinde Volcano, Kamerun, Africa	W. T.
38.39	.150	do	do	Do.

ORDER 9. FINNARE.

RANG 1. IJOLASE.

SUBRANG 2. MADUPOSE.

(III. 9, 1, 2.)

42.65	0.139	Madupite	Leucite Hills, Wyo	Bull. 168, 85.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SUBRANG 4. IIVAAROSE.

(III. 9, 1, 4.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
45.64	0.342	Nephelite-porphyry	Umptek, Finland	Fennia, XI, 2, 196.—W. T.
43.70	.257	Ijolite	Kuusamo, Finland	B. C. G. F., XI, 16.—W. T.
42.18	.268	Nephelite-basalt	Bauersberg, Bavaria	R. T., 1879, LXII.

SUBRANG 5. IJOLOSE.

(III. 9, 1, 5.)

42.07	0.281	Ijolite	Kuusamo, Finland	B. C. G. F., XI, 16.—W. T.

CLASS IV. DOFEMANE.

ORDER 1. HUNGARARE.

SECTION 1. MINNESOTIARE.

RANG 1. MINNESOTASE.

SECTION 1. MINNESOTIASE.

SUBRANG 2. COOKOSE.

(IV. 1, 1, 1, 1, 2.)

51.83	0.005	Pyroxenite	Meadow Creek, Mont	Bull. 168, 114.—W. T.
50.64	.020	Wehrlite	New Braintree, Mass	Bull. 168, 33.—W. T.
46.96	.030	Hypersthene-gabbro	Gunflint Lake, Minn	Bull. 168, 81.—W. T.

SECTION 2. ——.

RANG 1. ——.

SECTION 2. ——.

SUBRANG 1. BELCHEROSE.

(IV. 1, 2, 1, 2, 1.)

48.63	0.008	Peridotite	Belchertown, Mass	Bull. 168, 30.—W. T.

SUBRANG 2. ——.

(IV. 1, 2, 1, 2, 2.)

48.91	0.013	Olivine-gabbro	Orange Grove, Md	Bull. 168, 44.—W. T.
46.56	.050	Gabbro	Pharkowsky-Ouwal, Ural Mountains.	O. N., 145.
46.56	.043 (46.9)	do	Near Koswinsky, Ural Mountains	Do.
46.06	.098	Missourite	Shonkin Creek, Mont	Bull. 168, 133.—W. T.
44.94	.000	Wehrlite	Koswinsky, Ural Mountains	O. N., 173.
44.39	.032	Gabbro	Pharkowsky-Ouwal, Ural Mountains.	O. N., 145.

Classified list of analyses used in constructing diagrams—Continued.

SECTION 3. HUNGARIARE.

Rang 1. Wehrlase.

SECTION 1. WEHRLIASE.

Subrang 2. Wehrlose.

(IV. 1, 3, 1, 1, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
48.95	0.040	Wehrlite	Red Bluff, Mont	Bull. 168, 114.—W. T.
46.13	.001	Hornblende-picrite	Meadow Creek, Mont	Do.
45.68	.000	Lherzolite	Baldisser, Piedmont, Italy	Rosenbusch, El., 165.

SECTION 2. ——.

Subrang 2. Rossweinose.

(IV. 1, 3, 1, 2, 2.)

47.75	0.027	Peridotite	Cathay Hill, Mariposa County, Cal	Bull. 168, 209.—W. T.
46.00	.035 (46.1)	Hornblendite	Col d'Eret, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
44.99	.028	Wehrlite	Crystal Falls, Mich	Bull. 168, 67.—W. T.

SECTION 4. ——.

Rang 1. Cortlandtase.

SECTION 1. CORTLANDTIASE.

Subrang 1. Cortlandtose.

(IV. 1, 4, 1, 1, 1.)

44.64	0.000	Lherzolite	Lherz, Pyrenees	C. G. I., VIII, 1901, 833.—W. T.
36.80	.049	Peridotite	Syracuse, N Y	Bull. 168, 38.—W. T.

Subrang 2. Custerose.

(IV. 1, 4, 1, 1, 2.)

46.03	0.041	Peridotite	Silver Cliff, Colo	Bull. 168, 147.—W. T.

SECTION 5. PYRENIARE.

Rang 1. Lherzase.

SECTION 1. LHERZIASE.

Subrang 1. Lherzose.

(IV. 1, 5, 1, 1, 1.)

41.50	0.036	Hornblende-lherzolite	Caussou, Pyrenees	C. G. I., 1901, VIII, 833.—W. T.

Subrang 2. Argeinose.

(IV. 1, 5, 1, 1, 2.)

39.25	0.038	Hornblende-peridotite.	Argein, Pyrenees	C. G. I., 1901, VIII, 833.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SECTION 3. VENANZIASE.

SUBRANG 2. VENANZOSE.

(IV. 1, 5, 1, 3, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
41.43	0.152	Venanzite............	San Venanzo, Umbria, Italy..........	A. W. B., 1899, VII, 113.—W. T.

ORDER 2. SCOTARE.

SECTION 1. ——.

RANG 1. ——.

SECTION 1. ——.

SUBRANG 2. ——.

(IV. 2, 1, 1, 1, 2.)

58.05	0.018	Augite-norite.........	Madras, India...........	W. T.

SECTION 3. BRANDBERGIASE.

SUBRANG 2. BRANDBERGOSE.

(IV. 2, 1, 1, 3, 2.)

45.05	0.030 (45.9)	Pyroxenite...........	Brandberg, Norway................. .	Q. J. G. S., L, 31.—W. T.

SUBRANG 3. ——.

(IV. 2, 1, 1, 3, 3.)

45.04	0.209	Nephelite-basalt......	Katzenbuckel, Odenwald, Baden	Rosenbusch, El., 357.

SECTION 2. PAOLIARE.

RANG 1. PAOLASE.

SECTION 2. ——.

SUBRANG 2. ——.

(IV. 2, 2, 1, 2, 2.)

47.41	0.031	Augite-peridotite.....	Peekskill, N. Y.........................	A. J. S., XXXI, 1886, 40.—W. T.
42.68	.077	Hornblende-basalt ...	Hauk, S. Rhone.........................	Rosenbusch, El., 309.
40.42	.038	Olivine-gabbro.......	Crazy Mountains, Mont...............	Bull. 168, 122.—W. T.
40.15	.000	Koswite..............	Koswinsky, Ural Mountains..........	O. N., 119.
39.59	.057	Nephelite-basalt	Ottendorf, Silesia........................	R. T., 1884, LXIV.

SECTION 3. PAOLIASE.

SUBRANG 2. PAOLOSE.

(IV. 2, 2, 1, 3, 2.)

41.41	0.000 (41.6)	Koswite..............	Koswinsky, Ural Mountains..........	O. N., 119.
38.39	.031 (37.5)	Jacupirangite........	Magnet Cove, Ark.......................	J. G., IX, 620.—W. T.
38.38	.022	.....do................	Sao Paulo, Brazil........................	Do.
36.51	.075	Eleolite-mica-syenite.	Magnet Cove, Ark.......................	Do.

Classified list of analyses used in constructing diagrams—Continued.

SECTION 3. TEXIARE.

RANG 1. TEXASE.

SECTION 1. MARQUETTIASE.

SUBRANG 2. MARQUETTOSE.

(IV. 2, 3, 1, 1, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
39.37	0.017	Peridotite............	Opin Lake, Mich......................	Bull. 168, 64.—W. T.

SECTION 2. UVALDIASE.

SUBRANG 2. UVALDOSE.

(IV. 2, 3, 1, 2, 2.)

40.32	0.080	Nephelite-basalt	Uvalde County, Tex.................	Bull. 168, 62.—W. T.
39.92	.063 (41.0)	.....do................	.....do..................................	Bull. 168, 63.—W. T.
39.16	.081	.....do................	Oberleinleiter, Baden.................	Rosenbusch, El., 357.
36.53	.108	Nephelite-melilite-basalt.	Wartenberg, Baden	Rosenbusch, El., 360.

SECTION 4. ——.

RANG 1. CASSELASE.

SECTION 2. CASSELIASE.

SUBRANG 1. ——.

(IV. 2, 4, 1, 2, 1.)

38.34	0.106	Limburgite...........	Rio de Janeiro, Brazil.................	T. M. P. M., XX, 304.
37.98	.121 (37.4)	Melilite-nephelite-basalt.	Hohenberg, Westphalia..............	Rosenbusch, El., 357.

SUBRANG 2. CASSELOSE.

(IV. 2, 4, 1, 2, 2.)

39.20	0.056 (38.6)	Dike-rock	Kola Peninsula, Finland.............	Fennia, 15, 2, 1899, 27.—W. T.
37.96	.066	Nephelite-melilite-basalt.	Uvalde County, Tex	Bull. 168, 63.—W. T.

SECTION 5. ——.

RANG 1. ——.

SECTION 1. KALTENIASE.

SUBRANG 3. KALTENOSE.

(IV. 2, 5, 1, 1, 3.)

34.98	0.101	Mica-peridotite.......	Kaltenthal, Harzburg, Harz Mts.....	Rosenbusch, El., 165.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

Order 3. Sverigare.

SECTION 1. BERGENIARE.

Rang 1. Bergenase.

SECTION 1. BERGENIASE.

Subrang 3. Bergenose.

(IV. 3, 1, 1, 1, 3.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
31.59	0.032	Ilmenite-norite.......	Storgangen, Norway	B. M. A., 1896, V, 165.—W. T.

SECTION 2. ——.

Rang 1. ——.

SECTION 2. ——.

Subrang 2. ——.

(IV. 3, 2, 1, 2, 2.)

38.20	0.122	Nephelite-melilite-basalt.	Burgstall, Baden	Rosenbusch, El., 360.—W. T.
38.18	.036	(?) Pyroxenite........	Predazzo, Tyrol	E. K., II, 76.—W. T.

SECTION 3. AVEZACIASE.

Subrang 3. Avezacose.

(IV. 3, 2, 1, 3, 3.)

31.80	0.026	Avezacite	Avezac-Prat, Pyrenees	C. G. I., VIII, 1901, 832.—W. T.

Order 4. Adirondackare.

Suborder 2. Adirondackore.

Rang 1. Adirondackase.

SECTION 1. ADIRONDACKIASE.

Subrang 3. ——.

(IV. 4, 2, 1, 1, 3.)

24.74	0.000	Iron ore	Ulfö, Sweden..........................	S. M. Q., XXI, 60.
22.87	.000	Iron ore	Cumberland Hill, R. I	S. M. Q., XXI, 60.
14.95	.000	.....do	Laanghult, Sweden	Do.

Subrang 4. ——.

(IV. 4, 2, 1, 1, 4.)

21.42	0.033	Iron ore	Elizabethtown, N. Y	S. M. Q., XX, 343.
11.73	.055	.....do	.....do	Do.
10.37	.057	.....do	Frontenac County, Ontario	S. M. Q., XX, 331.

Classified list of analyses used in constructing diagrams—Continued.

Suborder 3. Champlainore.

RANG 1. CHAMPLAINASE.

SECTION 1. CHAMPLAINIASE.

SUBRANG 4. ——.

(IV. 4, 3, 1, 1, 4.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
17.90	0.000	Iron ore..............	Split Rock mine, N. Y................	S. M. Q., XX, 343.
13.35	.000	.....do................	Tunnel Hill, N. Y.....................	Do.

ORDER 5. ——.

Suborder 2. ——.

RANG 1. ——.

SECTION 1. ——.

SUBRANG 4. ——.

(IV. 5, 2, 1, 1, 4.)

10.77	0.039	Iron ore..............	Pine Lake, Ontario.....................	S. M. Q., XX, 331.

SUBRANG 5. ——.

(IV. 5, 2, 1, 1, 5.)

10.26	0.000	Iron ore..............	Iron Mountain, N. Y.................	S. M. Q., XX, 343.

SECTION 2. ——.

SUBRANG 4. ——.

(IV. 5, 2, 1, 2, 4.)

9.79	0.000 (9.5)	Iron ore..............	Millford Pit, N. Y.....................	S. M. Q., XX, 344.

CLASS V. PERFEMANE.

ORDER 1. MAORARE.

SECTION 1. CAROLINIARE.

RANG 1. WEBSTERASE.

SECTION 1. MARICIASE.

SUBRANG 1. MARICOSE.

(V. 1, 1, 1, 1, 1.)

55.52	0.000	Lherzolite............	Locano, Piedmont.....................	Rosenbusch, El., 165.
55.23	.000	Pyroxenite...........	Marico district, Transvaal............	A. J. S., VII, 1899, 318.—W. T.

Classified list of analyses used in constructing diagrams—Continued.

SECTION 2. WEBSTERIASE.

SUBRANG 1. WEBSTEROSE.

(V. 1, 1, 1, 2, 1.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
55.14	0.005	Websterite	Webster, N. C	Bull. 168, 53.—W. T.
53.98	.000	.....do	Hebbville, Md	Bull. 168, 43.—W. T.
52.55	.004	.....do	.....do	Bull. 168, 43.—W. T.

SUBRANG 2. CECILOSE.

(V. 1, 1, 1, 2, 2.)

53.21	0.003	Websterite	Cecil County, Md	Bull. 168, 43.—W. T.
53.25	.008 (53.6)	Pyroxenite	Mount Diablo, Cal	Bull. 168, 213.—W. T.

SECTION 2. MARYLANDIARE.

RANG 1. BALTIMORASE.

SECTION 2. BALTIMORIASE.

SUBRANG 2. BALTIMOROSE.

(V. 1, 2, 1, 2, 2.)

50.80	0.000 (50.6)	Pyroxenite	Johnny Cake road, Md	Bull. 168, 42.—W. T.
49.35	.000	Koswite	Koswinsky, Ural Mountains	O. N., 119.

SECTION 3. ——.

RANG 1. ——.

SECTION 2. ——.

SUBRANG 2. KOSWOSE.

(V. 1, 3, 1, 2, 2.)

43.20	0.00	Koswite	Koswinsky, Ural Mountains	O. N., 119.

SECTION 4. ——.

RANG 1. ——.

SECTION 1. ——.

SUBRANG 1. ——.

(V. 1, 4, 1, 1, 1.)

41.43	0.00	Saxonite	Riddles, Oreg	Bull. 168, 221.—W. T.

SUBRANG 2. ——.

(V. 1, 4, 1, 1, 2.)

42.39	0.000	Peridotite	Goose Bay, Straits of Magellan	W. T.

Classified list of analyses used in constructing diagrams—Continued.

SECTION 5. MAORIARE.

RANG 1. DUNASE.

SECTION 1. DUNIASE.

SUBRANG 1. DUNOSE.

(V. 1, 5, 1, 1, 1.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference..
42.80	0.000	Dunite	Dun Mountains, New Zealand	Rosenbusch, El., 165.
40.11	.000	Dunite	Corundum Hills, N. C	Bull. 168, 54.—W. T.
39.99	.00 (39.7)	Harzburgite	Olivine Hills Range, New Zealand	Rosenbusch, El., 165.

ORDER 2. ———.

SECTION 2. ———.

RANG 1. ———.

SECTION 2. ———.

SUBRANG 2. ———.

(V. 2, 2, 1, 2, 2.)

43.87	0.000	Lherzolite	Johnny Cake road, Md	Bull. 168, 42.

SECTION 5. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 2. PERMOSE.

(V. 2, 5, 1, 1, 2.)

31.84	0.000	Dunite sidéronitique.	Koswinsky, Ural Mountains	O. N., 128.

ORDER 3. ———.

SECTION 4. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 2. ———.

(V. 3, 4, 1, 1, 2.)

21.25	0.000	Iron ore	Taberg, Sweden	S. M. Q., XXI, 60.

Classified list of analyses used in constructing diagrams—Continued.

ORDER 4. ———.

Suborder 2. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 2. ———.

(V. 4, 2, 1, 1, 2.)

Silica content.	Alkali-silica ratio.	Author's name.	Locality.	Reference.
20.85	0.000	Iron ore	Cumberland Hill, R. I	S. M. Q., XX, 351.

SUBRANG 4. ———.

(V. 4, 2, 1, 1, 4.)

16.17	0.000	Iron ore	Iglamala, Sweden	S. M. Q., XXI, 60.
7.82	.088	.....do	Horton, Renfrew County, Canada	S. M. Q., XX, 331.

ORDER 5. ———.

Suborder 2. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 2. ———.

(V. 5, 2, 1, 1, 2.)

4.08	0.092	Magnetite-spinelite	Routivara, Sweden	Z. P. G.

SUBRANG 3. ———.

(V. 5, 2, 1, 1, 3.)

7.52	0.080	Iron ore	Leeds County, Ontario	S. M. Q., XX, 331.
6.88	.000	.....do	Alnö, Sweden	S. M. Q., XXI, 60.

SUBRANG 5. ———.

(V. 5, 2, 1, 1, 5.)

3.67	0.000	Iron ore	Mill Pond pit, N. Y	S. M. Q., XX, 344.
2.02	.000	.....do	Mayhew Iron Range, Minn	S. M. Q., XX, 337.
1.47	.000	.....do	Eagle Lake mine, Frontenac County, Ontario.	S. M. Q., XX, 331.
.87	.000	.....do	Sanford, N. Y	S. M. Q., XX, 344.

SUBORDER 3. ———.

RANG 1. ———.

SECTION 1. ———.

SUBRANG 4. ———.

(V. 5, 3, 1, 1, 4.)

0.76	0.000	Iron ore	Iron Mountain Wyo	S. M. Q., XX, 354.

DISCUSSION OF THE DIAGRAMS.

GENERAL DIAGRAMS.

On Pl. I are exhibited the comparative values of the chief chemical components of over 950 rocks. The relative molecular proportions of six oxides—Al_2O_3, K_2O, Na_2O, CaO, MgO, and FeO ($=FeO+2Fe_2O_3$)—are expressed by the shapes of the individual diagrams, the silica percentages are expressed by the relative lateral positions of these diagrams, and the comparative richness in alkalies is shown by the shapes of the individual diagrams and is also expressed by their relative vertical positions.

In the upper left-hand corner of the plate a smaller multiple diagram shows the distribution of the analyses in a more concise manner, the several colors of the spots indicating the classes into which they may be subdivided, according to the quantitative system, to be noticed more fully on page 68.

VARIATIONS IN COMPOSITION.

From the large diagram it is seen how manifold and intricate are the variations in chemical composition of igneous rocks. The larger the yellow triangles, the richer the soda and alumina; the larger the green ones, the more the potash and alumina; the taller the upper half of the individual diagram, the more the alumina; the narrower and taller the yellow and green triangles, the greater the excess of alumina over alkalies; the larger the blue triangles, the more the magnesia and lime; the larger the red triangles, the more the iron oxide and lime; the longer these lower triangles in the direction of the middle vertical line, the more the lime. Long, narrow, inclined, blue triangles indicate an excess of magnesia over lime; long, narrow, inclined, red triangles, an excess of iron oxide over lime.

The variation in the sizes of the individual diagrams, from the small ones at the left to the large ones at the right, corresponds to the great difference in silica content of the different rocks, as well as to differences in the components just named. Rocks with 75 per cent of silica have only 25 per cent of other constituents, while rocks with 40 per cent of silica have 60 per cent of other components. Moreover, the relative number of molecules for given percentages of mass increases with the decrease in molecular weight of the component oxides. It is to be observed that rocks high in silica are relatively high in alumina and the alkalies. The molecular weights of these are: Al_2O_3, 102; K_2O, 94; Na_2O, 62. Rocks low in silica may be high in alumina and alkalies, or high in lime, iron oxide, and magnesia. The molecular weights of the latter are: FeO, 72; CaO, 56; MgO, 40. The lightness of magnesia accounts for its greater proportions in the diagrams than in the analyses.

There are chemical variations which are somewhat regular, and others which seem irregular. First, it appears that the most siliceous rocks are rich in alumina and alkalies, and that lime increases at first more than iron and magnesia. But to this latter statement there are many exceptions.

In rocks with intermediate silica, 50 to 60 per cent, there is a gradation from those rich in alumina and alkalies and low in lime, iron, and magnesia to those rich in the latter and poor in the former. But there are rocks in this series high in alumina and lime and poor in alkalies and iron and magnesia.

The rocks low in silica, containing 35 to 50 per cent, have a wide range in variation, and attain the highest amount of magnesia. Those extremely low in silica, containing less than 30 per cent, are very rich in iron, with little or no alumina and alkalies, and little lime or magnesia.

The diagrams of rocks with less than 28 per cent of silica are found on Pl. VII. They are not repeated on Pl. I, because of the inconvenience of a plate of such length.

If the variations are studied in greater detail it is seen that in rocks having nearly the same silica and alkali ratios there is variation in the alumina, scarcely two rocks having the same amount. But there is more variation in the potash and soda. These values seem to be constantly shifting from place to place, with nothing suggesting a constant ratio between them. The great preponderance of soda is expressed by the predominance of yellow triangles over green ones. Dominantly potassic rocks are rare. They are more abundant among the more siliceous ones. Soda reaches its maximum in less siliceous rocks. Similar variability shows itself in the proportions of lime, iron oxide, and magnesia, whether these are subordinate or preponderant constituents.

TRANSITIONS AND EXTREMES.

It is possible to select certain shaped diagrams as types and discover many that are approximately the same. But closer inspection shows gradual variations from any two of these types to intermediate forms. And the general impression obtained from the whole assemblage is a regular variation from highly aluminous alkalic, yellow, and green figures to highly ferromagnesian calcic, red, and blue ones, combined with a very irregular variation in detail among adjacent figures.

The extremes of chemical variation reached in igneous rocks are exhibited in some of the diagrams. However, all known extremes are not expressed, because chemical analyses are wanting in several instances. Thus the extreme of pure silica attained by some intrusive dikes or veins of quartz is not represented. Chemical analyses have not yet been made of such rocks, or of the highly quartzose pegmatites with more than 85 per cent of silica. When they have been made the individual diagrams will extend to the extreme left-hand point of the multiple diagram.

Individual diagrams, composed of only a green triangle, exhibit the composition of a rock almost wholly orthoclase and quartz. One that is simply a yellow triangle is an almost pure albite rock. An almost pure nephelite rock from Ontario has been described by Adams, but analyses of it have not yet been made.

Diagrams consisting of only a narrow line represent an almost pure magnesium silicate, olivine, while those consisting of long triangles sloping to the left (Pl. VII) represent iron and titanium oxide—titaniferous magnetite.

The extremes of variability expressed in mineral terms are known to be as follows: Igneous rocks wholly quartz, almost wholly feldspar, orthoclase, albite, labradorite, and other varieties of feldspar, and those wholly nephelite; rocks almost wholly enstatite, hypersthene, olivine, magnetite. From what is known of the variable mineral composition of igneous rocks it is clear that with more analyses to introduce into the diagrams the variations in the shapes of the figures would be increased. Enough are shown to demonstrate the gradual character of the variations in chemical composition, and the transitions from rocks of one composition to those of another.

RELATIVE ABUNDANCE OF DIFFERENT KINDS OF ROCKS.

The distribution of the individual diagrams in the multiple one, and of the spots in the small composite diagram of Pl. I, shows that those varieties of rocks having extreme compositions, occurring in the margin of the multiple diagram, are less abundant than those having more nearly an average composition. This is still more evident when all those analyses are taken into account which were omitted because of lack of space for them. They will be found to belong to the central portion of the multiple diagram.

This is shown on Pl. VIII in a composite diagram exhibiting the variation in silica and alkali-silica ratio of 2,000 igneous rocks, which has been prepared by combining data found in this paper with those contained in the collection of analyses published by Washington,[a] to whom the author is indebted for an opportunity to study the collection in proof sheets. There are more than twice as many rocks involved in this diagram as in that on Pl. I, but the results are similar, and if the spots were replaced by individual diagrams the effect would be to doubly confirm all the conclusions drawn from a study of Pl. I. The construction of such a multiple diagram, however, is not feasible at this time.

The average rock, as calculated by Clarke[b] from 680 analyses of American rocks, is shown by diagram at 59.77–0.088, and that calculated by Harker[c] from 397 British rocks is shown by diagram at 58.7–0.083. These diagrams resemble those of rocks having like silica and alkali-silica ratios, and occur in the densest part of the assemblage. Other averages made from greater numbers of analyses yield almost identical results. A later average, made by Clarke[a] from 830 complete analyses of American rocks combined with 180 additional determinations of silica, 90 of lime, and 130 of alkalies, produce an average magma with 59.71 per cent of silica, and other constituents very nearly the same as those expressed in the diagram. Washington[b] obtained a closely similar average magma from 1,811 analyses of igneous rocks from all parts of the world, having 58.24 per cent of silica. The loci of the averages of American and of British rocks are marked by crosses on the diagram on Pl. VIII.

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[a] Op. cit.

[b] Bull. U. S. Geol. Survey, No. 148, p. 12.

[c] Geol. Mag., 1899, p. 220.

These prove that the average of a large number of known rocks is like the commonest rocks; conversely, that the commonest rocks are like the average of all known rocks; from which it is possible to derive all kinds of igneous rocks by processes of separation, splitting up (*spaltung*), differentiation. It does not follow from this that they have been produced from one common average magma, or even that they have been produced in this manner in actual fact; but such an origin is shown to be quantitatively possible and reasonable.

ABSENCE OF CLUSTERING.

A study of the diagrams of Pl. I and Pl. VIII fails to detect any clustering or grouping of analyses in definite parts of the multiple diagram, such as might serve as the basis for a chemical classification of rocks. This is the same as stating that there do not appear any "natural" recognizable subdivisions of rocks on a basis of their chemical composition. Variations in seven prominent chemical factors exist throughout the system of igneous rocks, the mathematical expression of which would be extremely intricate. The study of the chemical composition of igneous rocks by graphical methods does not reveal any simple method of grouping or classifying them on a basis of their chemical constituents alone.

SIMILARITY OF ROCKS FROM DIFFERENT PETROGRAPHICAL PROVINCES.

Further study of the diagrams and of the list of analyses shows the chemical similarity of many rocks that belong to different petrographical provinces. One illustration of this is taken from the best-known province, that of Christiania, made classic by the publications of Brögger. The diverse rocks of this region that are genetically related may be found in various places in the list and in the multiple diagrams. A comparison of the individual diagrams with those of similar shape from other petrographical provinces will demonstrate the truth of Brögger's statement that "the same group of differentiated rocks can be produced by separation from mother magmas of quite different chemical composition."[a] A list of the chief cases of similarity is given briefly, as follows:

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[a] Clarke, F. W., Bull. U. S. Geol. Survey No. 168, 1900, p. 14.

[b] Washington, H. S., Chemical analyses of igneous rocks from 1884 to 1900: Prof. Paper U. S. Geol. Survey No. 14, 1903, p. 107.

Table showing similarity between Norway rocks and those of other regions.

Place in classified list.	Norway rock.	Similar rocks of other regions.
I. 3, 1, 3	77.20–0.080	77.05–0.080, Butte, Mont.
		77.03– .080, Pikes Peak district, Colo.
	76.73– .077	77.33– .079, Alaska, and others.
I. 4, 1, 3	76.05– .092	76.20– .091, New Mexico.
		75.71– .094, Yellowstone Park, and others.
	71.49– .109	71.67– .101, Castle Mountain district, Mont.
		72.06– .107, Stony Creek, Conn.
		70.23– .113, Essex County, Mass.
I. 4, 2, 3	75.74– .086	76.00– .087, California.
		75.01– .086, Alaska.
		74.95– .088, Nevada.
	70.54– .107	71.88– .095, Iron Mountain, Mo.
		70.92– .096, Yellowstone Park.
		68.36– .105, Essex County, Mass.
I. 5, 1, 3	66.13– .130	66.03– .132, Custer County, Colo.
	64.04– .160	65.43– .140, Mount Ascutney, Vt.
I. 5, 1, 4	64.92– .146	65.51– .143, New Mexico.
	64.54– .157	63.71– .159, Essex County, Mass.
		63.09– .164, Essex County, Mass.
		62.17– .156, Crazy Mountains, Mont.
		61.05– .147, Ischia, Italy.
I. 5, 2, 4	59.38– .125	63.49– .138, Custer County, Colo.
		61.43– .133, Pantellaria.
		58.94– .109, Silver Cliff, Colo.
		58.28– .112, Crazy Mountains, Mont.
		57.48– .118, Pikes Peak district, Colo.
I. 6, 1, 4	58.61– .194	59.20– .189, Madagascar.
		58.70– .190, Crazy Mountains, Mont.
		58.64– .195, Cripple Creek, Colo.
		58.62– .191, Madagascar.
		58.20– .190, Madagascar.
II. 5, 2, 3	58.00– .142	59.78– .140, Custer County, Colo.
II. 5, 2, 4	59.56– .125	58.42– .099, Luzon, Philippine Islands.
	56.79– .118	57.97– .116, Mount Ascutney, Vt.
		57.01– .124, Silver Cliff, Colo.

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[a] Brögger, W. C., Quart. Jour. Geol. Soc. London, vol. 50, 1894, p. 36.

Table showing similarity between Norway rocks and those of other regions—Continued.

Place in classified list.	Norway rock.	Similar rocks of other regions.
II. 5, 3, 4	52.91–0.119	52.97–0.107, Pikes Peak district, Colo.
		53.10– .134, Madagascar.
	48.06– .084	49.24– .092, Ferdinandea.
		48.90– .090, Vosges.
		50.56– .079, Plumas County, Cal.
III. 5, 3, 4	47.90– .094	48.22– .084, Mount Ascutney, Vt.
		47.16– .077, New York.
III. 6, 3, 4	43.65– .071	42.03– .053, Arkansas.
IV. 2, 1, 1, 3, 2	45.05– .030	46.56– .043, Ural Mountains.
		46.56– .050, Ural Mountains.

From this list it appears that among the various rocks, ranging from persalic to dofemic, that occur in the Christiania region there are those whose chemical composition is very similar to particular rocks found in the Ural Mountains, Vosges Mountains, Ischia, Pantellaria, Ferdinandea, Madagascar, Luzon, Vermont, New York, Massachusetts, Connecticut, Missouri, Arkansas, Colorado, New Mexico, Nevada, Yellowstone National Park, Montana, California, and Alaska. These regions belong to diverse petrographical provinces, some of them very similar to that of Christiania, but others distinctly different.

There are provinces in Finland, in Canada, and in parts of the United States closely resembling the Christiania province in the characters of their nephelite-bearing rocks, but the regions are not identical in petrography. It is possible to find all degrees of similarity between petrographical provinces in various parts of the world, and the most intricate web of similar differentiation products may be woven by their comparison.

From the chemical character of igneous magmas, their content of like elements, the chemical character of the rock-making minerals, the fixed composition of some of them, and the serial variation in the composition of others, the theory of differentiation leads us to expect diversity in the rocks of all petrographical provinces of such a kind that identical or closely similar varieties of rocks will occur in otherwise unlike provinces.

CLASSIFICATION OF IGNEOUS ROCKS.

From the foregoing considerations it is evident that if we attempted to classify igneous rocks on a basis of their groupings in petrographical provinces—that is, if we should unite in the first instance rocks that are said to be genetically related—we should separate in the system rocks of world-wide occurrence that are alike.

It must not be forgotten that igneous rocks are not like biological organisms, and that we are constantly misleading ourselves by the use of biological terms, such as generation, consanguinity, and family, into imagining that the relationships of various rocks should be treated like the relationships of organisms.

When we have had more experience in the synthesis and the differentiation of molten rock magmas in chemico-physical laboratories; have handled them like other solutions of salts, which have been studied at lower temperatures; have solidified them under diverse physical conditions, we shall no doubt free ourselves from the fascination of biology and look upon rocks as the chemist looks upon a solidified mass of mixed salts. Is it not possible, in the period of preparation of such properly equipped laboratories, to anticipate their psychological effects and to think of the study of igneous rocks, their magmas and relationships, as purely physico-chemical problems, involving the measurement and comparison of mass and force, and their definite quantitative expression?

It being evident from the diagrams that there are gradual transitions in the chemical composition of igneous rocks from one extreme to another, that there are no recognizable groupings of rocks or noticeable subdivisions of the chemical series, and that chemically similar rocks occur in genetically different families, it follows that the subdivision of all igneous rocks into groups for purposes of classification must be along arbitrarily chosen lines. And the intricate character of the chemical variations, apparent in the diagrams, prevents a simple quantitative statement of any possible limits which may be selected for subdivisions of the series, however arbitrarily chosen. A careful study of the diagrams will convince one of the truth of this statement. It is a problem involving at least seven variable factors, and in its exact statement still more. It is the problem of expressing quantitatively the chemical composition of solutions of mixed salts often containing identical elements. The most artificial method of statement would be to consider the elements regardless of the possible salts in solution. A less artificial method would seem to be one which takes into account the salts which may enter the solution or may separate from it. In rock magmas the salts in solution may properly be considered to have the composition of those minerals which separate and crystallize when the magmas solidify. But it is understood that salts in solution may become split up into molecules of simpler composition, may be partially dissociated into ions, and may be combined in more than one manner in the act of separating from solution under diverse conditions.

When it is remembered that igneous rocks are solidified and for the most part crystallized mixed solutions, the expression of their chemical composition in terms of the separated salts or minerals developed in them is eminently reasonable. These principles underlie the quantitative classification of igneous rocks proposed by Cross, Pirsson, Washington, and the author.

In expressing the chemical composition of the rocks in terms of the minerals developed it is advisable to reduce the complex possibilities by selecting the simpler and commoner minerals as standards of comparison. The details of the method must be learned from the published essay,[a] to which the reader is referred if he is not already familiar with it.

CLASSIFIED DIAGRAMS.

The resulting chemical subdivision and grouping of igneous rocks by the method of quantitative classification recently proposed can be well shown graphically by the diagrams already described. The clearest exposition, however, requires a greater number of multiple diagrams than has been prepared, in order to separate all the divisions established by the classification. But the expense of publication has prevented the carrying out of such a plan, and so fewer multiple diagrams have been used, with a consequent loss of simplicity and a greater complexity than exists in the actual system of classification itself. The advantages to be derived from the exposition made, however, are sufficient to warrant its publication. It presents the salient features and results of the classification in a manner which can not be conveyed by words.

Multiple diagrams have been prepared to exhibit the grouping and variations in rocks belonging to the five classes of the quantitative system. Those of the first, second, and third classes are represented on three separate diagrams, while those of Classes IV and V are placed on one diagram because of their smaller number. The diagrams are presented in two forms—in one form spots represent the distribution of loci of analyses and their range of variation with respect to silica and alkalies; the other form is an individual diagram showing the variations with respect to the principal chemical components. (Pls. III, IV, V, VI, and VII.)

The distribution of the analyses belonging to the five classes, with respect to silica and alkalies, is shown by the spotted diagrams on Pls. III, IV, and V and by the differently colored spots in the composite diagram on Pl. I, in which the yellow spots belong to Class I, the red spots to Class II, the blue ones to Class III, and the black ones to Classes IV and V.

Since Class I is persalic, that is, is extremely rich in salic minerals—quartz and aluminous feldspathic minerals—most of these rocks occur in the diagram near the curved lines showing the positions of rocks composed wholly of quartz with albite or orthoclase, and albite with nephelite, or orthoclase with leucite. But rocks of this class include all those rich in alumina, which may form anorthite, a nonalkalic mineral. Consequently they also occur in the diagram remote from the curved lines, approaching the locus of anorthite at 43.160.-0.0.

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[a] Quantitative classification of igneous rocks. Chicago, 1903. Also Jour. Geol., vol. 10, 1902.

Class II is dosalic, that is, dominantly salic. There are less feldspathic minerals and more ferromagnesian ones, and since the latter are mostly low in alkalies, rocks of this class occur in the diagram farther from the limiting alkali-feldspathic curves than those of Class I.

As Class III is still richer in ferric minerals and lower in alkalies, rocks of this class occur still more removed from the curves just mentioned. The same is true to a greater degree for rocks of Classes IV and V.

It is seen that the positions of these classes of rocks overlap one another more or less in the composite diagram on Pl. I, hence the confusion of individual diagrams in the large multiple diagram of Pl. I.

DIAGRAMS OF CLASS I.

Let us consider separately the diagrams of the different classes of rocks, beginning with Class I. The persalanes, represented by 412 individual diagrams, being characterized by preponderant salic minerals, are subdivided into nine orders, according to the proportions of quartz and feldspars and of feldspars and feldspathoids (lenads). The order highest in quartz, perquaric, is highest in silica, and that highest in lenads, perlenic, is lowest in silica. Consequently the nine orders follow one another from left to right in the multiple diagram (Pls. II and III). The limits of the orders may be shown graphically for extreme cases, and may be interpolated for intermediate ones. Owing to the difference in the molecular weight of sodium and potassium, the limits for orders based on quartz and soda-feldspar (albite) and on quartz and potash-feldspar (orthoclase) do not coincide. Further, the greater chemical difference between the soda-lenad, nephelite, an orthosilicate, and the potash-lenad, leucite, a metasilicate, causes a still wider divergence between the boundaries of the orders based on albite and nephelite on the one hand and on orthoclase and leucite on the other. That is to say, the limits between the nine orders of persalic rocks vary according as the alkalies in the rocks are soda or potash. This is shown by the diagram on Pl. II. The black lines nearly at right angles to the upper curve mark the limits of the nine orders for ideal rocks composed wholly of quartz, albite, anorthite, or of soda-nephelite, albite, anorthite. The red lines transverse to the upper red curve mark the limits of the nine orders for rocks composed wholly of quartz, orthoclase, anorthite, or of leucite, orthoclase, anorthite.

The division lines for soda orders start from points on the quartz-albite-nephelite curve situated where q : ab :: 7 : 1; q : ab :: 5 : 3; q : ab :: 3 : 5; q : ab :: 1 : 7; ab : ne :: 7 : 1; ab : ne :: 5 : 3; ab : ne :: 3 : 5; ab : ne :: 1 : 7, and run to points on the quartz-anorthite line and the anorthite-nephelite line were q : an :: 7 : 1; q : an :: 5 : 3; q : an :: 3 : 5; q : an :: 1 : 7; an : ne :: 7 : 1; an : ne :: 5 : 3; an : ne :: 3 : 5; an : ne :: 1 : 7. The same may be said of the division lines for potash orders, substituting the names of orthoclase and leucite for those of albite and nephelite, respectively.

The diagram on Pl. II shows that the first four orders in each case nearly coincide, the boundary lines for potash rocks lying a little to the right of those for soda rocks. That is, the limit for each quaric order of potash rocks reaches a little lower silica than that for the corresponding orders of soda rocks.

The diagram also shows that the last four orders in each case differ more and more widely as they become more lenic. The range for the potash rocks is much more restricted than for the soda rocks, and the limits of orders for the potash rocks are higher in silica than for the corresponding soda rocks. This is because the potash lenad, leucite, is a metasilicate with 55.0 per cent SiO_2, while the soda lenad, nephelite, is an orthosilicate with 42.3 per cent SiO_2.

Since most rocks contain both soda and potash, the limits for the orders will occur between the extremes illustrated on Pl. II, varying with the ratio between soda and potash in each case. This explains the confused arrangement of the lenic orders in the upper right-hand portion of the diagram of persalic rocks on Pl. III.

In this diagram the number of the order of each rock is given by the first figure under its individual diagram. The number of the rang is given by the second figure. A study of these numbers will show that in the left-hand portion of the large diagram there is general concordance among the individual diagrams with respect to orders and rangs, except near the borders between orders, and between rangs. But in the right-hand upper portion of the large diagram there is great confusion of orders. It will be noted that where diagrams of different orders occur close together that with the higher number is the more potassic, other things being equal. The confusion would disappear if diagrams were constructed to exhibit the various subrangs. The correspondence between the distribution of the persalic rocks according to orders in the multiple diagram on Pl. III and the theoretical limits of the orders as shown on Pl. II is apparent. The orders form belts transverse to the curves which are the limits to ideally pure alkalic persalic rocks, namely, those consisting wholly of quartz, alkali-feldspars, or lenads.

As the wholly alkalic rocks occur along the limiting curves just mentioned and those free from alkali occur on the bottom line of the diagram, it follows that the various rangs of persalic rocks occur at intervals between these limiting lines; the peralkalic nearest the upper curves, the percalcic nearest the bottom line.

The boundary lines between the 5 rangs of persalic rocks are shown in the diagram on Pl. II. The black lines nearly parallel to the upper curve mark the limits for those based on soda alone; the red lines for those based on potash alone. Since most rocks contain both alkalies the limit for rangs will shift according to the ratio between soda and potash in the rocks. The rangs form belts roughly parallel to the limiting curves and bottom line of the multiple diagram. The limiting lines are drawn from the point of pure quartz, where they all become zero, to points on lines marking the middle of the perfelic order, 5—that is, the lines for mixtures of albite and anorthite in the case of pure soda rocks, and that for mixtures of orthoclase and anorthite for pure potash rocks. The points on these lines occur in the first case where Na_2O:CaO::7:1; Na_2O:CaO::5:3; Na_2O:CaO::3:5; Na_2O:CaO::1:7. They occur in the second case where K_2O:CaO::7:1, etc. From these points the limiting lines pass to corresponding points on lines representing mixtures of nephelite and anorthite and of leucite and anorthite.

From Pl. II it is seen that the range of rangs is nearly concordant in the quaric orders of persalic rocks and more and more divergent in the more lenic orders according as the rocks compared are more sodic or more potassic. This explains the apparent confusions of rangs in the right-hand portion of Pl. III.

There is a close correspondence between the distribution of the persalic rocks according to rangs in the large diagram (Pl. III) and the theoretical limits of rangs shown in Pl. II. This is shown by the second figure under each individual diagram.

The diagram on Pl. II exhibits the limitations of orders and rangs of the persalic rocks containing lenads. These are seen at the right end of the diagram. The limiting lines representing combinations of nephelite and anorthite and of leucite and anorthite cut diagonally across the belts of orders and rangs. Thus in soda rocks whose limits are shown by black lines order 9 has only rang 1; order 8 contains rangs 1 and 2; order 7 embraces rangs 1, 2, and 3; order 6 has four rangs—1, 2, 3, and 4, while all five rangs occur in order 5. In potash rocks, represented by red lines, the conditions are not quite so simple, as is seen in the diagram. Each of the lenic orders has a little larger range in calcic content and includes a small amount of a more calcic rang than occurs in the purely soda rocks.

There are variations in composition in rocks not yet taken into consideration which further modify the distribution and arrangement of the individual diagrams. Most rocks contain femic components, and these are generally low in alkalies or free from them. With increasing amount of nonalkalic femic components the limits of rangs in the multiple diagram shift downward, for rangs are established on the ratio between salic alkalies and salic lime—that is, between the K_2O and Na_2O and the CaO in the standard feldspars and lenads. Consequently the more femic minerals present, the less salic, and the smaller the alkalies necessary to maintain a given ratio with diminished salic lime. Hence the boundary line between rang 1 and rang 2 occurs farther below the limiting quartz-feldspar lenad curves the greater the amount of nonalkalic femic components in rocks. This is evident on comparing rangs in Pls. III and IV.

In the majority of rocks in which there is more alumina than alkalies there is usually more lime than is sufficient to satisfy the excess of alumina, so that the ratio between salic alkalies and salic lime, which determines the rang, is dependent on the amount of alumina in the rock. From this it happens that rocks having like silica percentages and alkali-silica ratios, located near one another in the multiple diagram, may differ in rang because of differences in alumina. Other things being equal, those with higher alumina will have lower ratios between salic alkalies and salic lime; and conversely, those with lower alumina will have higher alkali-calcic ratios. And these differences may affect the rang of the rocks compared. Examples of this kind are more evident in diagrams of rocks of Class II, and are found at 56.3–0.065 and 56.7–0.066, also 56.6–0.074 and 56.9–0.074, on Pl. IV.

Where the femic components of persalic rocks are alkalic the rocks are always in peralkalic rang 1, so that the limit of rang 1 is extended downward in the multiple diagram. The individual diagrams for rocks of this kind are characterized by comparatively short Al_2O_3 lines, less than the sum of K_2O and Na_2O.

The effect of increasing amounts of femic components in persalic rocks upon the limits of orders is not so easily appreciated, the relations being less simple. If we compare two rocks with like silica and alkali percentages, which would occur near one another in the diagram (Pl. III), the more nonalkalic femic components the less salic; that is, the less alumina and the less anorthite. If the rocks are quaric the ratio between quartz and feldspar is increased by decreasing the anorthite feldspar. But the substitution of FeO, MgO, or CaO for Al_2O_3 would require more SiO_2 to form metasilicates than that required to form anorthite, consequently the free SiO_2, quartz, would be reduced, but to a smaller amount than the feldspar is reduced, consequently the ratio between the quartz and feldspar would be higher in the rock with more nonalkalic femic components. The limits between the quaric orders would shift to the right.

If the rocks are lenic, containing nephelite, sodalite, or leucite, a reduction of anorthite feldspar would increase the ratio between lenads and feldspars. A substitution of FeO, MgO, or CaO for Al_2O_3 in amount equal to the CaO of presupposed anorthite would necessitate their conversion to metasilicates according to the method of the quantitative classification under discussion. This would require more silica than is required by anorthite, so that the amount of alkali feldspars would be reduced and the lenad-feldspar ratio further increased. In case the lime were replaced by magnesia and iron oxide and converted into orthosilicates there would be slight change in the silica available for the salic components, because of the general preponderance of magnesia in such rocks, and its lighter molecular weight and consequent greater number of molecules. Hence, in most cases an increase of femic components would increase the lenad-feldspar ratio, and the limits between lenic orders of persalic rocks would shift toward the left.

In the less frequent cases in which alkali femic components occur, the limits between all orders shift to right or left according to the relative proportions of the alkali-femic components and according as they are acmite or are free from ferric iron.

The occurrence of magnetite, ilmenite and other mitic components also modifies the position of the ordinal limits, but in peralkalic rocks these constituents generally occur in such small amounts that their effects may be disregarded in the interpretation of the diagram under consideration.

With respect to subrangs it may be said that in the great majority of cases they can be recognized by a comparison of the yellow and green triangles representing the relative amounts of soda and potash in the rock. For in most instances all of the alkali is salic. In other cases where part of it is femic, the ratio between the salic alkalies can be made out by a scrutiny of the triangles and a comparison of the amounts of alkalies and alumina expressed by the lengths of the potash, soda, and alumina lines. The ratio in this case would be

$$\frac{K_2O}{Al_2O_3-K_2O}.$$

In general, where alumina is in excess of the sum of the alkalies, a comparison of the triangles named, or of the lengths of the potash and soda lines, will determine the subrang to which the rock belongs. Those in which $\frac{K_2O}{Na_2O} > \frac{7}{1}$ are in perpotassic subrang 1; those with $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$ are dopotassic subrang 2; when $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$ the subrang is 3, sodipotassic; when $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$ it is dosodic, subrang 4; and with $\frac{K_2O}{Na_2O} < \frac{1}{7}$ the subrang is 5, persodic.

These divisions apply only to the first three rangs. In the fourth rang, which is docalcic, there are only three subrangs, namely: 1, $\frac{K_2O}{Na_2O} > \frac{5}{3},$ prepotassic; 2, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5},$ sodipotassic; 3, $\frac{K_2O}{Na_2O} < \frac{3}{5},$ presodic. The fifth rang being precalcic, subrangs are not recognized.

A study of the diagrams on Pl. III shows that soda preponderates over potash in most persalic rocks; that sodipotassic rocks, subrang 3, are the most numerous; that dopotassic rocks are rare, and perpotassic ones extremely so. The numbers of rocks in the 5 rangs are 3, 31, 201, 156, 21.

Variations in the femic components, FeO, MgO, and femic CaO, are noticeable in the individual diagrams and represent differences among the subordinate mineral constituents of the rocks. Their quantity is so small that they may be neglected in the magmatic classification of these persalic rocks.

The diagrams plotted together demonstrate the gradual transition between orders of rocks of Class I, as well as between rangs and subrangs. And since any individual diagram may represent a large body of igneous rock or a small facies of one, and since any of the diagrams may represent rock bodies of considerable importance, it follows that all parts of the series may be of equal importance geologically or petrologically, and consequently rocks that happen to belong on the border line of any set of subdivisions into which the whole rock series must be divided, for purposes of classification of any kind, may be as important as those situated at the center of such an arbitrary division, and in some regions it will happen that such rocks are the most important.

When the student has become convinced of the continuity of the chemical series of igneous rocks he will not be surprised to discover that a rock of great importance belongs on the boundary of a classificatory division, or probably falls on both sides of a division line. It will not affect the importance of the rock or militate against the value of the system of classification. It will simply be a "natural" fact. And the system of classification will appear to him as "natural" as any other system which attempts to classify igneous rocks.

DIAGRAMS OF CLASS II.

The multiple diagram of 335 dosalic rocks of Class II (Pl. IV) may be readily interpreted by comparison with that of Class I (Pl. III). The spotted diagram to the left shows the distribution of the analyses with respect to silica and alkalies. The rocks are for the most part lower in alkalies than those of Class I, because the femic components are generally nonalkalic. The few cases with rather high alkalies contain acmite molecules, which fact is indicated in the individual diagrams by pronounced iron oxide and soda and by low alumina. Several of these occur in the left-hand part of the multiple diagram at 74.35–0.092, 69.02–0.121, etc.

The dominant constituents in dosalic rocks being the same as those in the persalic rocks, nine orders have been established, in the same manner as in Class I. Rangs and subrangs also correspond to those in Class I. So there is the same general arrangement of individual diagrams in Pl. IV, according to orders and rangs, as in the multiple diagram of Class I, with the modifications produced by increasing amounts of femic components, for the most part nonalkalic. The belts of orders are transverse to the limiting quartz-alkali-feldspar lenad curves. The limits of rangs are lower than in the diagram of Class I. There is the same confusion of orders and rangs along the division lines consequent upon variations in alumina and femic components, and a like diversity of alkalies, shown by the yellow and green triangles, with a strong preponderance of soda over potash. The greatest number of rocks are dosodic. The numbers in each rang are: 0, 17, 126, 183, 9.

With an increase in the femic components the variations in iron oxide, magnesia, and lime become more noticeable and important, and it is necessary to recognize distinctions among the subordinate femic components, that is, to note grads and subgrads. The nature of the grads can not be determined directly from the diagrams because it depends on the amount of available silica, which may be combined with femic bases to form silicates, pyroxene, olivine, or akermanite, and also on the amount of ferric oxide and titanium oxide. The ferric oxide is blended with ferrous oxide in the diagrams and is not indicated graphically. Titanium oxide is so small in most dosalic rocks that it is not introduced into the diagrams in this Class II.

It is to be noted, however, that the silica is sufficiently high to form silicates of almost all the femic bases, and ferric oxide is in most cases low, so that the great majority of dosalic rocks belong to the prepolic grad 1, that in which the femic silicates—pyroxene and olivine—preponderate over the femic nonsilicates—magnetite, hematite, ilmenite, rutile, and the silico-titanate, titanite.

As to the subgrad to which these rocks belong, by far the largest number contain nonalkalic femic components, and therefore fall in the premirlic subrang 1. A small number contain alkalic femic components in nearly the same proportions as nonalkalic ones, and fall in the alkalimirlic subrang 2. Some, characterized by highly alkalic femic constituents, such as acmite, belong to subrang 3.

The multiple diagram for Class II (Pl. IV) exhibits similar transitions between orders and between rangs as those shown by the diagram for Class I, and permits the same conclusions to be drawn from it. The chemical series will appear more and more complete as more varieties of rocks are analyzed.

DIAGRAMS OF CLASS III.

The chemical relations of the salfemic rocks, Class III, are expressed graphically on Pl. VI. Two of them are so high in silica that they have been plotted on Pl. IV with rocks of Class II. One is rockallose, with 73.60 SiO_2, 0.091 $\frac{\text{alk.}}{SiO_2}$. It is intermediate between Classes III and II. The other is a pantellerite, with 68.75 SiO_2, 0.144 $\frac{\text{alk.}}{SiO_2}$. It is also intermediate between Classes III and II.

The distribution of the rocks with respect to silica and alkalies is shown in the upper diagram of Pl. V. The location of the analyses in the multiple diagram is still farther from the limiting curves than in Class II, and the silica ranges lower. The alkali-silica ratios reach high values in some cases. TiO_2 is present in notable amount in a number of instances.

It will be observed that the lower half of the individual diagrams is the larger in nearly every case, but the long, narrow, upper triangles indicate that there is more alumina than alkalies, and that part of the lime is salic, so that the salic components are more nearly equal to the femic than appears at first glance.

There are but two rocks in quarfelic order 3, those mentioned above, and plotted on Pl. IV. Very few occur in order 4. The greatest number are perfelic, order 5, and the lenic orders are well represented.

Most of the perfelic rocks are alkalicalcic, rang 3, or docalcic, rang 4. The few that are peralkalic or domalkalic are low in alumina, as, for example, 54.2–0.160 and 45.2–0.085. It is noticeable also in the lenic salfemanes, orders 6, 7, 8, and 9, that the domalkalic character of the salic minerals in a number of rocks is due to low alumina rather than to high alkalies, as 50.00–0.110, 46.00–0.121, and 42.7–0.139.

There are great variations in the shapes of the diagrams of rocks nearly alike in silica and alkali-silica ratio. A few rocks are rich in potash, notably those from Leucite Hills, Wyoming, 54.08–0.163, and others. A greater number are rich in soda, occurring in the upper part of the multiple diagram. But the majority are sodipotassic and dosodic.

Since in these rocks the femic minerals are equal or nearly equal to the salic, and in some cases are more abundant, they are as characteristic of the rocks as the salic minerals. The salfemanes differ considerably with respect to these constituents, which is plainly shown by differences in the shapes of the lower part of the individual diagrams. Some are long in the direction of lime; others long in magnesia. Few have more iron oxide than magnesia. From this it follows that the grad, subgrad, and section of subgrad are as important in the classification of these rocks as are order, rang, and subrang.

The grad of these rocks can not be determined from the diagrams because it depends upon the proportions of ferromagnesian silicates and nonsilicates determined by the available silica and the ferric iron not allotted to acmite. It is to be remarked that the great majority of salfemic rocks included in the diagrams are dopolic, grad 2—that is, normative pyroxene and olivine dominate over magnetite, hematite, and ilmenite. In most of these rocks there is a notable amount of normative nonsilicates. The majority of these rocks are perpyric or dopyric, sections 1 and 2—that is to say, normative pyroxene preponderates over olivine.

The character of the subgrad is indicated by the diagrams, since this depends upon the proportion of alkalies that enter the femic minerals. With few exceptions the alumina is greater than the sum of the alkalies, so that the femic minerals are nonalkalic and the rocks belong to the permirlic subgrad 1. The exceptions to this are the two rocks rich in acmite—rockallose and the rock near varingose.

The diagrams also show that most of these salfemanes are domiric, section 2, ferrous oxide and magnesia dominating over femic lime. This, however, is not perfectly evident in the diagrams because of the lack of information concerning ferric iron and the necessity of deducting salic lime from the total lime.

Finally, when it is remembered that nearly half the molecules of iron oxide belong to ferric oxide, the diagrams show that in most cases the rocks are domagnesic, subsection 2, with magnesia dominant over ferrous iron. In a few instances they are permagnesic, which is indicated by long, narrow, blue triangles.

DIAGRAMS OF CLASSES IV AND V.

The diagrams of dofemic and perfemic rocks, Classes IV and V, are plotted together on Pl. VII. This has been done because of the comparatively small number of analyses of these rocks at hand and the desire to economize space. The distribution of these rocks with respect to silica and the alkalies is shown in the lower diagram on Pl. V. As should be expected, these rocks are far from the quartz-alkali-feldspathic curve, are low in alkalies, and extend to the lowest limit of silica. The diagram of one rock comparatively high in alkalies falls outside the area of Pl. VII, and is not represented. The rock is a nephelite-basalt from Katzenbuckel, Odenwald (45.04–0.209). Individual diagrams belonging to rocks of Classes IV and V are designated by Roman numerals, IV and V, before Arabic ones denoting orders and sections of orders.

The arrangement of the individual diagrams in the multiple one is in accord with the general system adopted with special reference to the great majority of rocks, the more salic ones. The rocks of Classes IV and V are less than one-tenth of all that are represented in the diagrams. Their arrangement is related to one component of prime importance, silica. But alkalies are extremely subordinate and would not properly be chosen as a basis for their coordination were these rocks considered by themselves. However, their relations to the more salic rocks are exhibited by retaining the same system of arrangement.

The chief difference between the rocks of Classes IV and V lies in the amount of alumina, with which in general there is sufficient lime or alkalies to form salic feldspars or lenads. In one case only is the composition of the magma such as to require the assumption of salic corundum, the rock being magnetite-spinelite from Routivare, Sweden (4.08–0.092). Most all of the rocks containing alkalies belong to Class IV, but this class also embraces rocks without alkalies, the diagrams occurring on the zero line for alkali-silica ratios. Nearly all the rocks of Class V are so low in alkalies as to occur on the zero line. The higher ratios obtaining in several iron ores with 4 to 8 per cent of silica may easily be due to errors in chemical analysis, though, of course, they may be correct values.

Since dofemic and perfemic rocks are divided into orders according to the relative proportions of femic silicates and nonsilicates, and into sections of orders according to the proportions of femic metasilicates and orthosilicates, it follows that the five orders and sections range according to the silica content of the rock from perpolic order 1, perpyric section 1, with highest silica, 55.5, to permitic order 5, with lowest silica, 0.7. In like manner the various sections under each order range from higher to lower silica. These distinctions do not appear in the shapes of the diagrams, but in their lateral position in the multiple diagram.

With respect to rangs it happens that without exception all the rocks represented in this collection of analyses belong to permirlic rang 1, the alkalies which occur in the rocks being salic, which is shown in the diagrams by the alumina line exceeding the sum of those of the alkalies.

Sections of rangs and subrangs are based on the proportions of femic lime, magnesia, and ferrous oxide, but the proportions of ferrous and ferric oxide are not indicated in the diagrams. It is to be noted, however, that iron is generally subordinate to magnesia in most perfemic rocks with more than 28 per cent of silica, so far as they are represented in the collection of analyses; and when it is remembered that a part of this iron is ferric, it will be seen that the proportion of ferrous iron is smaller than appears in the diagrams.

While the lime is considerable in a large number of cases, it is very small in many of the rocks, and when salic lime is deducted it is found that the femic lime is subordinate to the magnesia and ferrous iron in nearly every instance. A majority of the dofemic rocks, Class IV, are domiric, section 2 of rang 1. A smaller number are permiric, section 1 of rang 1. In nearly every case these rocks are domagnesic, subrang 2. The iron ores of Class IV are perferrous, subrang 5.

The perfemanes, Class V, with the exception of the iron ores, are permiric and domiric in about equal numbers. Lime is subordinate to magnesia and iron. They belong to sections 1 and 2 of rang 1. In nearly every case these rocks are permagnesic, subrang 1. This is shown by the elongation of the magnesia line. The iron ores of course are perferrous, subrang 5. The abrupt change from the titaniferous iron ores, below 27 per cent silica, to the magnesium-rich rocks above this percentage of silica is very noticeable. It indicates that the intermediate transitional rocks which have been described by petrographers have not been analyzed.

The diagrams of the different classes of igneous rocks established by the quantitative system illustrate the chemical characters of the rocks grouped together by this system, and show the degrees of similarity and the ranges of variation within the different divisions of the classification so far as they exist in the rocks represented by the 977 analyses in the collection.

A greater number of multiple diagrams representing separate divisions of the system will give more definite graphic expression to these minor groups of rocks. Their preparation and publication at this time have not been feasible. It is possible, also, to devise individual diagrams which shall express more or less definitely the norm of each rock, but these would of necessity be so intricate that a larger scale of drawing would be required, entailing serious difficulties of publication.

It is believed that the simpler individual diagrams and more composite multiple ones here presented will serve a better purpose at this time in demonstrating graphically some of the chemical facts and relationships that have been used by Cross, Pirsson, Washington, and the author as the foundation on which they have constructed the quantitative system of rock classification.

CORRELATION OF IGNEOUS ROCKS CLASSIFIED BY THE QUANTITATIVE AND QUALITATIVE SYSTEMS.

The classified list of rocks already given shows the character of the correlation that may be made of the two systems of classification. The variety of names that appear within any one of the more common divisions of the quantitative systems is due in part to differences in chemical composition, which are recognized by subdivisions of the system of a lower order, as grad and subgrad. It is in part due to diversity of texture and mineral development, which is expressed in this system by terms qualifying the magma names. But it is also due to a great extent to essential differences in the bases of classification in the two systems and to the flexibility of qualitative definitions.

A brief tabulated statement of the salient features of the correlation is given, with some general remarks concerning the more common relationships. Greater detail must be gotten from the classified list and from the collection of rock analyses published by Washington.

CLASS I. PERSALANE.

1. Victorare.	2. Belgare.	3. Columbare.	4. Britannare.	5. Canadare.	6. Russare.	7. Tasmanare.	8. Ontarare.	9. ——.
Quartz-veins.	Quartz-pegmatite.	Granite.		Syenite, anorthosite.	Nephelite-syenite.			Nephelite-pegmatite.
	R. 1. Dargase. Quartz-pegmatite.	**R. 1. Alaskase.** Aplite. Granite. Alaskite. Tordrillite. Quartz-porphyry. Quartz-keratophyre. Rhyolite. Obsidian.	**R. 1. Liparase.** Aplite. Granite. Quartz-syenite. Syenite-porphyry. Grorudite. Quartz-pantellerite. Rhyolite. Paisanite. Comendite. Quartz-keratophyre. Obsidian.	**R. 1. Nordmarkase.** Syenite. Quartz-syenite. Neph.-syenite. Nordmarkite. Pulaskite. Umptekite. Albitite. Sölvsbergite. Keratophyre. Bostonite. Trachyte. Phonolite.	**R. 1. Miaskase.** Neph.-aplite. Neph.-syenite. Foyaite. Ditroite. Miascite. Mariupolite. Tinguaite. Heronite. Phonolite. Leucite-phonolite.	**R. 1. Laugenase.** Foyaite.	**R. 1. ——.** Neph.-syenite.	**R. 1. ——.** Neph.-pegmatite.
		R. 2. Alsbachase. Aplite. Granite. Alsbachite. Rhyolite.	**R. 2. Toscanase.** Aplite. Granite. Quartz-monzonite. Granodiorite. Diorite. Syenite. Quartz-syenite-porphyry. Rhyolite. Toscanite. Latite. Dellenite. Dacite. Trachyte. Andesite.	**R. 2. Pulaskase.** Quartz-syenite. Neph.-syenite. Pulaskite. Nordmarkite. Laurvikite. Sodalite-syenite. Diorite. Bostonite. Rhomben porphyry. Vulsinite. Keratophyre. Trachyte. Leucite-trachyte. Andesite.	**R. 2. Viezzenase.** Neph.-syenite. Neph.-rhomben porphyry. Neph.-tinguaite. Tinguaite.			

CLASS I. PERSALANE—Continued.

1. Victorare.	2. Belgare.	3. Columbare.	4. Britannare.	5. Canadare.	6. Russare.	7. Tasmanare.	8. Ontarare.	9. ——.
Quartz-veins.	Quartz-pegmatite.	Granite.		Syenite, anorthosite.	Nephelite-syenite.			Nephelite-pegmatite.
		R. 3. Riesenase. Granite. Quartz-diorite-porphyry. Toscanite. Vulcanite.	**R. 3. Coloradase.** Granite. Granodiorite. Quartz-diorite. Banatite. Diorite. Dacite. Andesite. Trachyte.	**R. 3. ——.** Syenite. Diabase-porphyrite. Andesite. **R. 4. Labradorase.** Anorthosite. **R. 5. Canadase.** Anorthosite.				

CLASS III. SALFEMANE.

1. ——.	2. ——.	3. Atlantare.	4. Vaalare.	5. Gallare.	6. Portugare.	7. Kamerunare.	8. Bohemare.	9. Finnare.
			Diorite and gabbro.		Lamprophyres and leucite-nephelite lavas.			
		R. 1. Rockallase. Rockallite. Pantellerite.		**R. 1. Orendase.** Orendite. Wyomingite.	**R. 1. Wyomingase.** Shonkinite. Camptonite. Nephelinite. Analcite-basalt.	**R. 1. Malignase.** Malignite. Theralite. Ijolite-porphyry.	**R. 1. Chotase.** Leucitite.	**R. 1. Ijolase.** Madupite. Ijolite. Nephelite-porphyry. Neph.-basalt.
				R. 2. Kilauase. Shonkinite. Syenite-lamprophyre. Mica-picrophyre. Absarokite. Basalt. Augitite.	**R. 2. Monchiquase.** Shonkinite. Leucite-syenite. Monchiquite. Vogesite. Tephrite. Leucite-basanite. Leucite-basalt. Nephelite-basalt. Limburgite.	**R. 2. Kamerunase.** Heumite. Theralite. Monchiquite. Farrisite. Leucite-basalt. Leucite-nephelinite. Haüynophyre. Basalt.	**R. 2. Albanase.** Ijolite. Nephelinite. Leucitite. Theralite. Leucite-tephrite. Limburgite.	
			R. 3. Vaalase. Quartz-gabbro. Olivine-diabase. Basalt.	**R. 3. Camptonase.** Kentallenite. Olivine-monzonite. Diorite. Gabbro. Essexite. Camptonite. Absarokite. Leucite-basanite. Neph.-basalt. Quartz-basalt.	**R. 3. Limburgase.** Neph.-gabbro. Ijolite. Camptonite. Monchiquite. Hornblende-basalt. Neph.-basanite. Limburgite. Augitite. Hornblendite.	**R. 3. Etindase.** Camptonite. Neph.-basalt.		

CLASS III. SALFEMANE—Continued.

1. ——.	2. ——.	3. Atlantare.	4. Vaalare.	5. Gallare.	6. Portugare.	7. Kamerunare.	8. Bohemare.	9. Finnare.
			Diorite and gabbro.		Lamprophyres and leucite-nephelite lavas.			
			R. 4. ——. Diorite. Melaphyre.	**R. 4. Auvergnase.** Gabbro. Norite. Dolerite. Ariegite. Fourchite. Monchiquite. Basalt.	**R. 4.** ——. Gabbro.			
			R. 5. ——. Olivine-gabbro-diabase.	**R. 5. Kedabekase.**[1] Gabbro. Norite. Kedabekite. Ariegite.				

CLASS IV. DOFEMANE.

1. Hungarare.	**2. Scotare.**	**3. Sverigare.**	**4. Adirondackare.**	**5. ——.**
Gabbro and peridotite.			Iron ores.	
S. 1. Minnesotiare. Gabbro. Wehrlite. Pyroxenite.	**S. 1. ——.** Augite-norite. Pyroxenite. Neph.-basalt.	**S. 1. Bergeniare.** Ilmenite-norite.		
S. 2. ——. Gabbro. Missourite. Wehrlite. Peridotite.	**S. 2. Paoliare.** Gabbro. Koswite. Jacupirangite. Augite-peridotite. Hornblende-basalt. Neph.-basalt.	**S. 2. ——.** (?) Pyroxenite. Avezacite. Neph. melilite-basalt.	**S. 2. Adirondackore.** Iron ore.	**S. 2. ——.** Iron ore.
S. 3. Hungariare. Wehrlite. Peridotite. Hornblende-picrite. Hornblendite. Lherzolite.	**S. 3. Texiare.** Peridotite. Neph.-basalt. Neph. melilite-basalt.		**S. 3. Champlainore.** Iron ore.	
S. 4. ——. Peridotite. Lherzolite.	**S. 4. ——.** Limburgite. Neph.-melilite-basalt.			
S. 5. Pyreniare. Hornblende-peridotite. Hornblende-lherzolite. Venanzite.	**S. 5. ——.** Mica-peridotite.			

CLASS V. PERFEMANE.

1. Maorare.	**2. ——.**	**3. ——.**	**4. ——.**	**5. ——.**
Peridotite and pyroxenite.		Iron ores.		
S. 1. Caroliniare. Websterite. Pyroxenite. Lherzolite.				
S. 2. Marylandiare. Pyroxenite. Koswite.	**S. 2. ——.** Lherzolite.		**S. 2. ——.** Iron ore.	**S. 2. ——.** Iron ore.
S. 3. ——. Koswite.				**S. 3. ——** Iron ore.
S. 4. ——. Saxonite.		**S. 4. ——.** Iron ore.		
S. 5. Maoriare. Dunite. Harzburgite.	**S. 5. ——.** Dunite sidéronitique.			

Approaching the subject from the standpoint of the qualitative, mineralogical system we are interested in the distribution of rocks in the quantitative system in the first instance according to their content of quartz, feldspar, feldspathoid, or ferromagnesian minerals. We may consider the distribution of, first, rocks containing a notable amount of quartz and their equivalent lava forms; second, rocks characterized by feldspar without notable amounts of quartz or feldspathoids; third, rocks containing notable amounts of feldspathoids; fourth, rocks composed chiefly of ferromagnesian minerals.

In general, it may be said that the quartzose igneous rocks fall almost without exception in Classes I, II, and III, and those in Class III are comparatively rare, so that most quartzose rocks belong to Classes I and II, and those with notable amount of quartz $\left(\frac{Q}{F} > \frac{1}{7}\right)$ are in orders 4 and 3, very few occurring in orders 2 and 1, and these only in Class I.

Nearly all rocks known as granite, granodiorite, quartz-monzonite, quartz-diorite, and the rare quartz-gabbros, together with their aphanitic and glassy equivalents, belong to order 4, Classes I and II, in most part, and to some extent to order 3 in Class I, very few being found in this order of Class II. The most quartzose rocks belong to Class I.

Of the minerals associated with quartz the most abundant and frequent are feldspars, usually preponderant, and these are distinguished in the qualitative system as alkalic, alkalicalcic, and calcic. Since it is generally true that as magmas are richer in magnesium and iron they also contain more calcium, it follows that rocks richer in ferromagnesian minerals usually carry more calcic feldspars than rocks poor in those minerals. Consequently the greater number of quartzose rocks with alkalic feldspars occur in Class I, and the greater number with calcic feldspars are in Class II; and those with the most calcic feldspar should occur in Class III. To this, of course, there are notable exceptions, especially where the femic mineral is not ferromagnesian but alkalic, as acmite, in rockallose.

Most granites are found in Class I, and most of these are in order 4, with dominant feldspars; fewer in order 3. Most of these persalanes are peralkalic and domalkalic, rangs 1 and 2. But in order 4 a considerable number are alkalicalcic, rang 3. The more alkalic rocks are commonly sodipotassic, while the alkalicalcic ones are mostly dosodic; that is, with increase of lime there is a diminution of potash.

These quartz-bearing persalanes include rocks that have been named aplite, granite, granitite, granodiorite, quartz-monzonite, quartz-diorite, the phanerocrystalline porphyries of these, and quartz-porphyry, rhyolite, dacite, and andesite, together with those of special varieties—alaskite, alsbachite, tordrillite, comendite, paisanite, toscanite, and others. Some rocks that fall within the limits of these divisions of the quantitative system bear names occurring mostly in other divisions, such as syenite, nordmarkite, diorite, andesite. These are in part intermediate rocks deserving double magma names; in part, those, like some andesites, whose mineral composition is not completely determinable, and in which the quartz content is obscure or uncrystallized.

A much smaller number of granites belong to Class II, dosalanes. The most alkalic members of this class, pantellerite and grorudite, are comparatively rich in ferric oxide.

Most of the quaric rocks of Class II are alkalicalcic and dosodic. The greater number of them bear the names quartz-diorite, diorite, and andesite.

The quaric rocks in Class III are low in quartz, except in the rare varieties of pantellerite and rockallite. But in the other rocks, also rare, quartz occurs in small amount with alkalicalcic feldspars and calcic feldspars. One of these rocks is quartz-gabbro, another a diorite, and several others olivine-bearing rocks, whose chemical analyses are such that they fall in order 4 of this class.

Rocks characterized by feldspars without notable amounts of quartz or feldspathoids occur in perfelic order 5 of Classes I, II, and III.

Among the perfelic persalanes, Class I, the more alkalic rocks are commonest (syenites), alkalicalcic ones are rare, while docalcic ones are well known (anorthosites). As to the character of the alkalies, soda preponderates in most cases, dosodic rocks being more abundant than sodipotassic ones, which, however, are common.

The names borne by these rocks are: Syenite, nordmarkite, pulaskite, laurvikite, bostonite, trachyte vulsinite, andesite, keratophyre, and others. The most sodic rocks have been called albitite; the most calcic, anorthosite. Some of them have been called nephelite-syenite, phonolite, leucite-trachyte, and other names.

The perfelic dosalanes, Class II, are more common than the extremely feldspathic persalanes, and the alkalicalcic ones are more numerous than the domalkalic or docalcic forms, but these are also well represented. Most of these rocks are dosodic, although many are sodipotassic.

They appear under the names of syenite, umptekite, monzonite, diorite, gabbro, norite, trachyte, ciminite, akerite, shoshonite, andesite, basalt, and others. They also include some rocks called granite, nephelite-syenite, leucite-trachyte, and kersantite.

The perfelic salfemanes, Class III, are alkalicalcic and docalcic, and most of them are dosodic. They embrace gabbro, norite, ariegite, kedabekite, camptonite, dolerite, and basalt. The more potassic and sodipotassic rocks of this class and order have been called kentallenite, absarokite, and lamprophyre. A few peralkalic rocks belonging here occur at Leucite Hills, Wyoming—orendite, wyomingite.

The rocks characterized by notable amounts of feldspathoids or lenads—leucite, nephelite, sodalite—with the exception of a few that belong in Class IV, fall within the lenic orders 6, 7, 8, 9 of Classes I, II, and III.

Lenic persalanes, Class I, are most abundant in order 6, with dominant feldspar, but they are known in each of the more lenic orders. They are mostly peralkalic and dosodic, some being sodipotassic. They have been named nephelite-syenite, foyaite, ditroite, miascite, phonolite, and tinguaite. Very few contain leucite.

The same is true for the lenic dosalanes, Class II. Most of them occur in lendofelic order 6, but the other lenic orders are represented.

In order 6 they are mostly peralkalic and domalkalic, and the majority are dosodic. They include nephelite-syenite, laurdalite, essexite, tinguaite, theralite, and others, besides some rocks called syenite, monzonite, diorite, and gabbro.

Rocks of the remaining orders are peralkalic and dominantly sodic. A few rocks in order 7 are sodipotassic.

Order 7 contains rocks called lujavrite, tinguaite, tephrite, leucitite, hauynophyre, and others.

Rocks of orders 8 and 9 are rare. The first embrace leucite-basanite, leucitite, and tinguaite. The ninth order is represented by urtite, an ijolite rich in nephelite, and sodipotassic arkite.

Lenic salfemanes, Class III, are about as numerous as lenic rocks in Classes I and II. They are more uniformly distributed through orders 6, 7, and 8. Perlenic rocks, order 9, are rare.

In order 6 there are more alkalicalcic rocks than in the corresponding order of Class II. Most of the rocks are sodipotassic and dosodic. The rocks have been called shonkinite, leucite-syenite, leucite-monchiquite, monchiquite, limburgite, basanite, and others.

In order 7 the rocks are dominantly alkalic and dosodic. They embrace malignite, theralite, nephelite-basalt, nephelinite, and others.

Order 8 is similar to order 7. The rocks are rarer and a few are dopotassic. They are theralite, ijolite, nephelinite, leucitite, and others.

The rocks of order 9 are peralkalic, and include dopotassic madupite of Leucite Hills, Wyoming, and dosodic ijolite, nephelite-porphyry, and nephelite-basalt.

Rocks with preponderant femic constituents, the dofemanes, Class IV, and perfemanes, Class V, are distinguished from one another by the presence in the former of a notable but subordinate amount of salic, feldspathic minerals and by their absence from the perfemanes. The dofemanes, then, contain either notable subordinate amounts of feldspar, leucite, nephelite, sodalite, or of aluminous ferromagnesian, alferric minerals.

In Class IV the five orders, based on the proportions of normative pyroxene and olivine, compared with magnetite, ilmenite, and other nonsilicates, are all represented. Orders 1 and 2 are most common. In each of these the more pyroxenic sections are better represented than the more olivinic. The rocks invariably belong to the permirlic rang, 1; that is to say, the femic minerals contain little or no alkali. In most cases ferrous oxide and magnesia preponderate over lime, and in the majority of rocks magnesia dominates over ferrous oxide.

In perpolic order 1 the rocks are known in the qualitative system as gabbro, olivine-gabbro, norite, koswite, peridotite, pyroxenite, jacupirangite, nephelite-basalt, nephelite-melilite-basalt, and limburgite.

In polmitic order 3, with nearly equal silicate and nonsilicate minerals, the few rocks as yet described have been called ilmenite-norite, pyroxenite, avezacite, and nephelite-melilite-basalt.

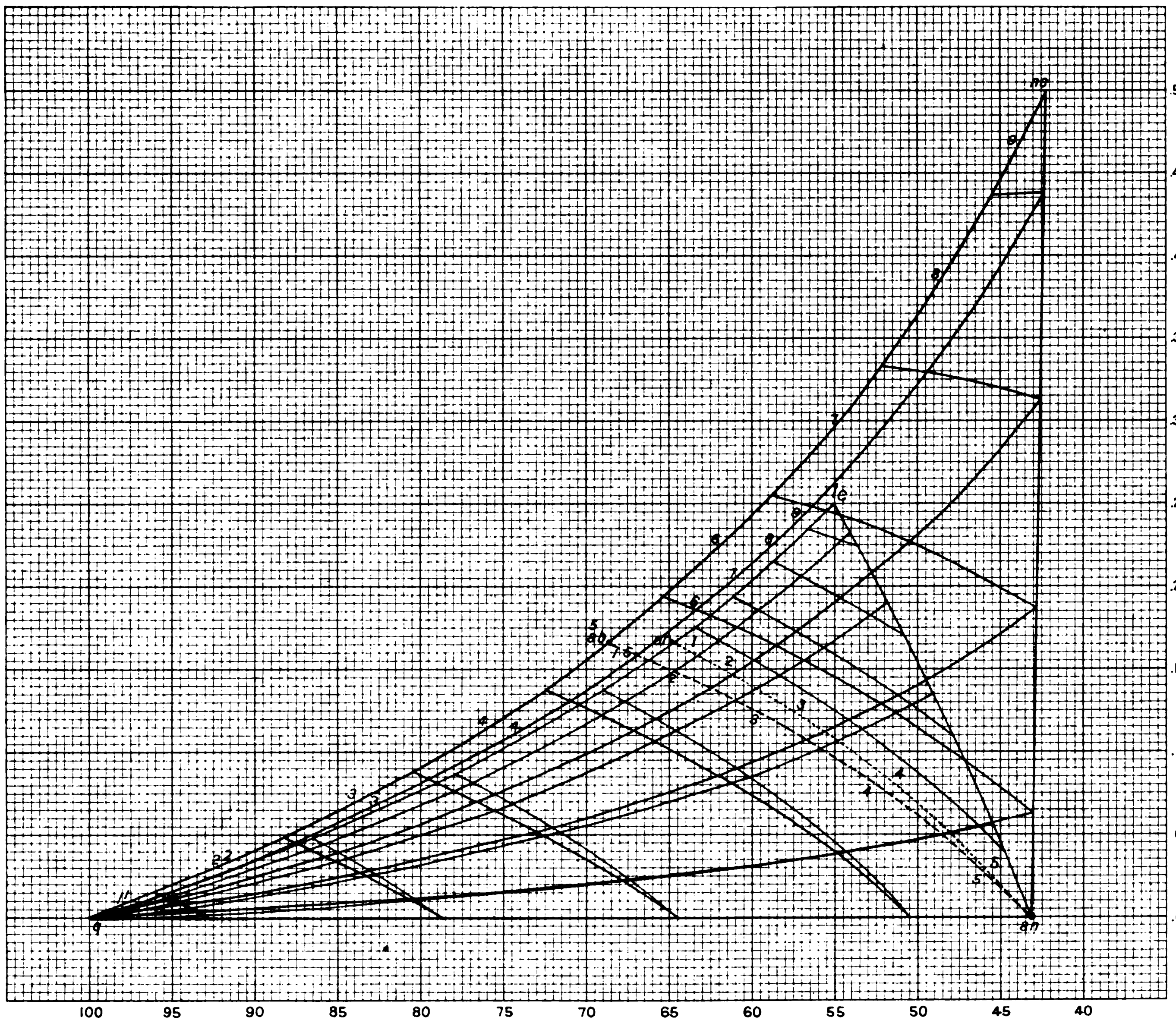
Orders 4 and 5, with preponderant magnetite and ilmenite, embrace certain feldspathic iron ores from Sweden, Canada, and New York State.

Rocks of Class V are comparatively rare; they have little or no feldspathic minerals or aluminous ferromagnesian minerals. Most rocks belong to perpolic order 1, and range from wholly pyroxenic to wholly olivinic kinds. A very few rocks fall within each of the other orders.

In order 1 the rocks have been called pyroxenite, websterite, koswite, peridotite, saxonite, harzburgite, and dunite.

In order 2, with notable, subordinate, nonsilicate minerals, occur a lherzolite, and dunite rich in iron ore.

In the other orders, 3, 4, and 5, the rocks are titaniferous iron ores, with variable amounts of ferromagnesian silicates. In one instance the rock consists of magnetite and spinel



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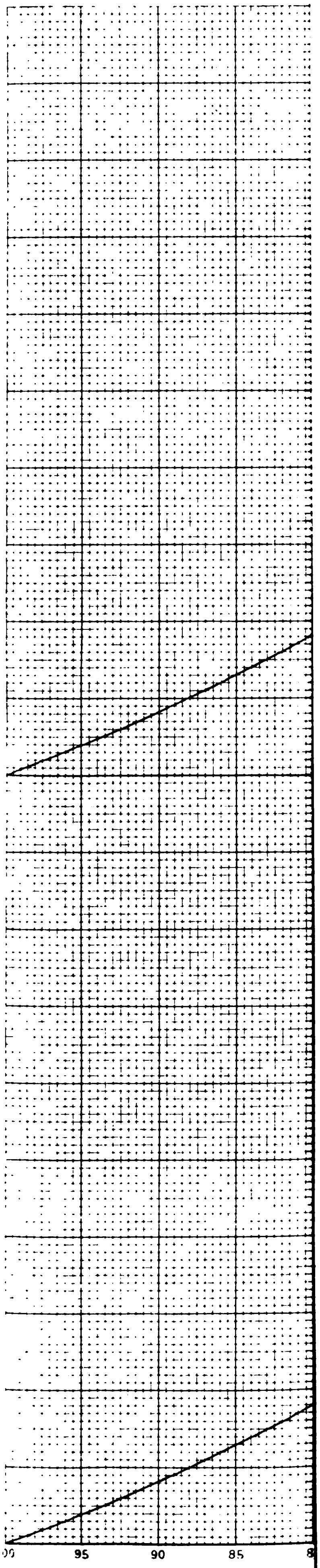

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